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ABSTRACT

Institutions of higher education in the United States appear to many to have the capacity to provide enough scientists and engineers to meet the nation's needs. However, many researchers, employers and policymakers are concerned that the future supply will be inadequate. In the early 1990s the United States will experience a decline in the number of college-age students. Fewer students seem to be interested in science and engieering careers. Women's interest in these careers appears to have plateaued and non-Asian minorities, traditionally poorly represented in science and technology careers, are forming an increasing proportion of American school children. The Office of Technology Assessment concludes that these shortages are not inevitable. This assessment: (1) examines the forces associated with elementary and secondary education that shape the talent pool; (2) traces pathways to undergraduate and graduate education in science and engineering; and (3) presents a discussion of policy areas for possible congressional action, developed under two strategies labeled "retention" and "recruitment." (CW)

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EDUCATING
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GRADE SCHOOL TO GRAD SCHOOL

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SE 049 166

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EDUCATING
SCIENTISTS AND ENGINEERS
GRADE SCHOOL TO GRAD SCHOOL

CONGRESS OF THE UNITED STATES   OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

The Nation relies on scientists and engineers to conduct research and development, teach, and meet the technical needs of industry and society. Ensuring an adequate supply of versatile and well-trained people poses several challenges to America's formal education system, from elementary school through graduate school. The House Committee on Science, Space, and Technology asked the Office of Technology Assessment to analyze the factors that will affect the supply of scientists and engineers in the foreseeable future.

American schools, colleges, and universities educate the scientists and engineers who replenish the technical work force. This report examines how and why students are drawn toward or deterred from pursuing a career in science or engineering. Schools, families, peers, informal education efforts—such as museums, science centers, special programs, and television—all play a role. The subtitle of this report—*Grade School to Grad School*—emphasizes that many factors and institutions must be understood as all one system.

The advisory panel, workshop participants, and other contributors to this study were instrumental in defining the major issues and providing a range of perspectives on them. OTA thanks them for their commitment of energy and sense of purpose. Their participation does not necessarily represent endorsement of the contents of this report, for which OTA bears sole responsibility.

John H Gibbons

JOHN H. GIBBONS
Director

Educating Scientists and Engineers: Grade School to Grad School Advisory Panel

Neal F. Lane, *Panel Chairman*
Provost, Rice University, Houston, TX

Amy L. Buhrig
Specialist Engineer
Artificial Intelligence
Boeing Aerospace Corp.
Seattle, WA

David M. Goodman
Deputy Director
New Jersey Commission on Science and Technology
Trenton, NJ

Irma S. Jarcho
Chairman
Science Department
The New Lincoln School
New York, NY

Hugh F. Loweth
Consultant
Annandale, VA

James L. Powell
President
Franklin and Marshall College
Lancaster, PA

Rustum Roy
Evan Pugh Professor of the Solid State
Materials Research Laboratory
Pennsylvania State University
University Park, PA

Bernard P. Sagik
Vice President for Academic Affairs
Drexel University
Philadelphia, PA

William T. Snyder
Dean, College of Engineering
University of Tennessee
Knoxville, TN

Peter D. Syverson
Director of Information Services
Council of Graduate Schools in the United States
Washington, DC

M. Elizabeth Tidball
Professor of Physiology
School of Medicine
The George Washington University
Washington, DC

Melvin R. Webb
Biology Department
Clark College
Atlanta, GA

F. Karl Willenbrock
Executive Director
American Society for Engineering Education
Washington, DC

Hilliard L. Williams
Director of Central Research
Monsanto Co.
St. Louis, MO

Dorothy S. Zinberg
Center for Science and International Affairs
Harvard University
Cambridge, MA

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Educating Scientists and Engineers: Grade School to Grad School

OTA Project Staff

John Andelin, *Assistant Director, OTA*
Science, Information, and Natural Resources Division

Nancy Carson
Science, Education, and Transportation Program Manager

Daryl E. Chubin, *Project Director*

Lisa Heinz, *Analyst*
Richard Davies, *Analyst*
Christine M. Courtney, *Research Assistant*
Duncan Brown, *Editor**
Marsha Fenn, *Administrative Assistant*
Christopher Clary, *Administrative Secretary*
Madeline Gross, *Secretary*
Leslie Ridenour, *Administrative Secretary*
Michelle Haahr, *Secretary*
Wendy Weingarten, *Intern*

OTA Contributors

John Alic
Kathleen Fulton
Karen Mathiasen
Robert Cook-Deegan
Kathi Hanna
Robert Niblock
Gary B. Ellis
Martha Harris
Edith B. Page
Michael Feuer
Nancy Lubin
Linda Roberts

Special Thanks To:

Alan Fechter, *National Research Council*
Shirley Malcom, *American Association for the Advancement of Science*
Betty M. Vetter, *Commission on Professionals in Science and Technology*

This report is dedicated to the memory of Eugene Frankel
OTA Project Director, December 1984-May 1986

---

*Contractor.

Contractors

Applied Systems Institute, Inc.
Richard Wabnick,
Principal Investigator

Harley Balzer
Georgetown University

William K. Cummings
Harvard University

Christopher J. Dede
University of Houston at Clear Lake

Robert E. Fullilove
University of California, Berkeley

Michael E. Gluck
Harvard University

Steven L. Goldman
Lehigh University

Kenneth C. Green
University of California, Los Angeles

Edward J. Hackett
Rensselaer Polytechnic Institute

Henry Hertzfeld
Consultant

Valerie E. Lee
University of Michigan, Ann Arbor

Arnold S. Levine
Consultant

Betty D. Maxfield
Consultant

National Research Council
Office of Scientific and Engineering Personnel

Guy R. Neave
University of London

John Reuss
Consultant

Vernon T. Savage
Towson State University

Betty M. Vetter
Commission on Professionals in Science and Technology

Iris R. Weiss
Horizon Research, Inc.

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Summary

American schools, colleges, and universities have the capacity to provide enough scientists and engineers to meet the Nation's needs. Historically, students and institutions have satisfied changing market needs, as evidenced by the response of engineering enrollments to the semiconductor industry boom of the late 1970s. However, many researchers, employers, and policymakers are concerned that future supply will be inadequate. In the early 1990s, the Nation will experience a decline in the number of college-age students, although some increase can be expected before the turn of the century. More important, fewer students, particularly those white males who have been the mainstay of science, seem to be interested in science and engineering careers. Women's interest in science and engineering, after rising for a long time, seems to have plateaued. Non-Asian minorities, traditionally poorly represented in science and engineering, will form a steadily increasing proportion of American schoolchildren.

Despite these changes, OTA concludes that shortages of scientists and engineers are not inevitable; the labor market will continue to adjust, albeit with transitory and perhaps costly shortages and surpluses. The Federal Government may need to play a more active role. Rather than trying to direct market responses, policy can aim to prepare a cadre of versatile scientists and engineers for research and teaching careers, invest in an educational system that creates a reservoir of flexible talent for the work force, and ensure opportunities for the participation of all groups in science and engineering.

The Federal Government has had both direct and indirect effects on the education of scientists and engineers, but it is only one of many actors in the system. The Federal role in science and engineering education is most significant at the graduate level, more diffuse at the undergraduate level, and small in elementary and secondary education.

Federal investment in science and engineering education and training is undertaken for many reasons; there is no single objective or mission. One class of investments is in direct support of graduate students and production capacity at blue-chip universities. Other investments are made in newer, developing colleges and universities with growth potential, and in undergraduate and precollege education. Federal support is spread across different types of institutions and students, partly because of the uncertainty of payoffs, and partly to ensure equality of access and geographical balance. Both short- and long-term investments are necessary in a marketplace where demographics, economics, and technology constantly change the criteria for success in education for the work force.

The educational process from grade school to graduate school is 20 years long. This means there are many possible Federal options for enriching the future supply of scientists and engineers. It is difficult, however, to distinguish which would have the most impact. At each level of the educational system, there are many choices for action. Few measures guarantee predictable effects in the relatively short term; most are more speculative and longer-term possibilities. Just as there are no imminent crises in replenishing the science and engineering work force, there are no quick fixes.

This assessment:

- examines the forces associated with elementary and secondary education that shape the talent pool;
- traces pathways to undergraduate and graduate education in science and engineering; and
- presents a discussion of policy areas for possible congressional action, developed under two strategies labeled "retention" and "recruitment."

Two Federal management issues are also identified. These are leadership and coordination among Federal agencies, and evaluation of trends and outcomes to define future policy actions that will improve the reach and content of science and engineering education. The overarching policy issue is whether the Federal Government allows the market for scientists and engineers to take its course or attempts to intervene more boldly.

The two broad strategies of retention and recruitment complement each other and would operate best in tandem (see table). The retention strategy is designed to invigorate the current science and engineering work force by reducing attrition of undergraduate and graduate students. Such short-term retention programs could increase output of scientists and engineers within a few years. In contrast,

Policy Options To Improve Science and Engineering Education

Recruitment—Enlarge the Pool

- *Elementary and secondary teaching*: encourage and reward teachers; expand support for preservice and inservice training.
- *School opportunities*: reproduce science-intensive schools; adjust course-taking and curricula; review tracking; and revise testing.
- *Intervention programs*: increase interest in and readiness for science and engineering majors; transfer the lessons from successful programs; encourage sponsorship from all sources.
- *Informal education*: increase support of science centers, TV, fairs, and camps.
- *Opportunities for women*: enforce Title IX of the Education Amendments of 1972 and provide special support and intervention.
- *Opportunities for minorities*: enforce civil rights legislation and provide special support and intervention.

Retention—Keep Students in the Pool

- *Graduate training support*: "buy" Ph.D.s with fellowships and traineeships; these people are most likely to join the research work force.
- *Academic R&D spending*: bolster demand and support research assistants, especially through the mission agencies.
- *Foreign students*: adjust immigration policy to ease entry and retention.
- *Undergraduate environments*: support institutions that reward teaching and provide role models, such as research colleges and universities, and historically Black institutions.
- *Hands-on experience*: encourage undergraduate research apprenticeships and cooperative education that impart career skills.
- *Targeted support for undergraduates*: link need- or merit-based aid to college major.

Strengthen Federal Science and Engineering Education Efforts

- *National Science Foundation as lead science education agency*: underscore responsibility through the Science and Engineering Education Directorate for elementary through undergraduate science programs.
- *Federal interagency coordination and data collection*—raise the visibility of science education and the transfer of information between agencies and to educational communities.

recruitment is a long-term strategy to enlarge the base of potential scientists and engineers by recruiting more and different students into science and engineering. Such a strategy entails working with schools and colleges, along with children, teachers, and staff, to renovate elementary and secondary mathematics and science education.

If the Nation wants more scientists and engineers relatively quickly, then retaining college and graduate students in science and engineering is the most useful policy strategy. Many able students leave science during college, after earning baccalaureate degrees, and during graduate school. Only about 30 percent of baccalaureate science and engineering graduates enter full-time graduate study, and nearly half of science and engineering doctoral candidates never earn Ph.D.s. Some loss is inevitable (and, indeed, beneficial to other fields), but those who leave unwillingly and prematurely are a rich resource that could be tapped. Because attrition rates are so high and the population of research scientists and engineers is relatively small, slight improvements in retention could increase significantly the number of scientists and engineers in the work force. Federal policies could work at all levels to retain more of these able, interested students in the pool.

Many factors affect students' career choice and persistence in science and engineering: interest and aptitude; perceptions about careers gleaned from university faculty, peers, and jobs; and anticipated earnings and other, nonmonetary rewards. Students considering academic careers must also weigh the burden of undertaking and financing graduate training. The Federal Government affects these career decisions through targeted support of students, universities, and research, and through its pervasive influence on the American economy and research agenda. The extent and form of Federal support for students, particularly graduate students, affects the attractiveness of further study. Federal research and development (R&D) support and national missions (e.g., in health, space, defense) shape students' perceptions of the job market for scientists and engineers, as well as the environments in which students are educated.

Many of the policies discussed in this report involve established mechanisms that could be expanded effectively. There are prepared college graduates and graduate students who, with the proven incentives of fellowships and R&D-supported jobs, could be attracted to science and engineering.

The basic goal of recruitment is to expand and improve the talent pool. The years to do this are elementary school through the first years of college. A particularly critical time is 6th through 12th grade, when course-taking becomes more specialized and career plans are formed. Policies to expand the mathematics and science talent pool differ from those to accelerate or improve the education of a small, science-oriented population. Students who take early, enthusiastic likings to science and mathematics can be served differently from those whose interests are still developing.

For all students, the content and quality of their elementary and secondary education determine their academic preparation for college, their likelihood of graduating from college, and their ability to derive the greatest benefit from a college education. Better high school graduates mean better college graduates, and ultimately better scientists and engineers. Increased participation for those students outside the traditional stereotype of college-bound science or engineering majors, such as many minorities and women, must begin with early changes in their preparation, awareness, and interest. They must first be prepared for and drawn into college and science majors before they can respond to graduate and R&D programs. The continuing low proportion of these groups in science and engineering indicates that the current educational system and career incentives must be made to work better. The end of expansion and transition to a steady state of enrollments and research funding will require universities, employers, and the Federal Government to adjust their models and mechanisms of science and engineering recruitment.

There are two demonstrably successful ways to recruit young people to science and engineering: offer special science and mathematics educational enrichment programs tailored to selected students, and give all students good, enthusiastic teaching. An area of lively innovation is informal education—science museums, television programs, camps, and other experiences outside the formal school system.

In the near term, policies can only be implemented with existing teachers, schools, textbooks, and equipment, in a system with multiple educational objectives. In the longer term, substantial improvements in recruitment might come through full-scale revision of elementary and secondary curricula, tracking, testing, and course structure. Such sweeping change should be undertaken with all students and all purposes of education in mind (not just science and engineering), and will be hard to achieve given the scale of American education and the inertia of the existing system.

The health of the U.S. economy, technological changes, and shifting government priorities, none of which can be projected with any useful degree of accuracy, all affect future demand for scientists and engineers. The demand has increased since World War II, and most analysts expect that growth to continue; but growth will vary significantly from field to field. The complexity of analyzing changes in demand for the relatively small science and engineering work force confounds forecasts, especially at the level of individual fields. Federal actions, because of their pervasive effects on the economy and on the size and location of R&D activities, have strong effects, both direct and indirect, on the demand.

Although comprising only 4 percent of American workers, scientists and engineers have specialized skills that are vital to the national welfare: they widen human understanding by doing basic research and by teaching, they develop and apply new technologies of every kind, and they keep the national physical infrastructure and manufacturing base running smoothly. Others trained as scientists and engineers, but not actively employed in research or product development, also contribute to our national well-being in other occupations. Historically, the demand for scientists and engineers has been rising. The Nation is well advised, therefore, to seek an adequate supply of people prepared for science and engineering careers.

Chapter 1

Introduction

Photo credit: Mathematics, Engineering, Science Achievement, Lawrence Hall of Science

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Chapter 1

Introduction

Scientists and engineers, although comprising only 4 percent of American workers, have specialized skills vital to the national welfare. They widen human understanding by doing basic research and teaching, they develop and apply new technologies of every kind, and they keep the national manufacturing base running smoothly. Many people trained as scientists and engineers, but not actively employed in research or product development, also contribute to the well-being of the United States by bringing strong quantitative skills and an understanding of science to other occupations and fields. The Nation is well advised, therefore, to seek an adequate supply of people equipped and able to work in science and engineering.[1]

Recent trends have raised doubts in some minds about the adequacy of the future science and engineering work force.[2] Declining birth rates portend lower college and university enrollments, and thus fewer science and engineering majors. Each successive college-age cohort also contains a larger proportion of ethnic and racial minorities,[3] which historically have been poorly represented in science and engineering. Furthermore, the number of women planning science and engineering majors, after a decade of steady increases peaking in the late 1970s, has plateaued. Their gains in science and engineering baccalaureate degree-taking have not compensated for the more dramatic declines in participation by white males in the mid-1970s. (Many white males, who in the past would have been likely to become scientists or engineers, in recent years have pursued majors in business instead; women are now following suit.) In general, interest in scientific and engineering careers, as indicated by annual surveys of incoming college freshmen, has been declining slightly for the last 3 to 5 years (although the annual output of baccalaureate science and engineering degrees is holding steady).[4]

These trends, combined with the past decade's sustained growth in science and engineering employment, have led some observers to forecast shortfalls in the science and engineering work force. The belief that the pattern of births determines the number of future scientists and engineers ("demographic determinism") is, however, open to question on a number of grounds:

- Women (and, to a lesser extent, Blacks and Hispanics) raised their rates of participation in science and engineering during the 1970s; while these gains seem to have leveled off in the 1980s, there is no reason to believe that participation cannot be further increased.
- Longitudinal surveys of students show that their choice of major and career plans change frequently, even up to the sophomore year of college, and their choices are influenced by market factors as well as by family and school.
- Elementary and secondary schools could do a better job of encouraging students in science and mathematics, thus expanding the talent pool.
- Ph.D. production has never tracked either the size of the birth cohort or the number of bac-

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[1] "Equipped and able" implies high "quality." Because there is no agreement on definitions, it is difficult to measure the quality of students and of the education they are receiving. Quality is a pervasive factor in a scientist's or engineer's education and professional work; it is also an attribute embodied by a group, suggesting that trained personnel possess the knowledge and skills that make them versatile enough to satisfy a particular market demand when it arises. This assessment assumes that excellence is a paramount goal of public policy.

[2] Definitions of "scientist" and "engineer," and therefore estimates of the number of each, vary considerably by source. Throughout this assessment, the category "scientists and engineers" includes social scientists. Analyses that refer to "natural scientists and engineers" exclude social scientists. Classifying people by kind of science or engineering degree (baccalaureate, master's, or Ph.D.), rather than kind of work performed, is the more reliable basis for gauging future supply, including an important subset and focus of this assessment—the "research work force." For further discussion, see U.S. Congress, Office of Technology Assessment, "Preparing for Science and Engineering Careers: Field-Level Profiles," staff paper, Jan. 21, 1987, pp. xv-xxii.

[3] Unless otherwise indicated, "minorities" refers to Blacks, Hispanics, and American Indians. Asian-Americans have the highest rates of participation in science and engineering of any group; thus, they are not considered with the other minorities. All of these analytical categories mask the heterogeneity within racial and ethnic groups, which is discussed below and in two forthcoming reports: U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering—A Technical Memorandum*, forthcoming, summer 1988; and U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering—A Technical Memorandum*, forthcoming, summer 1988.

[4] Alexander W. Astin et al., *The American Freshman: Twenty Year Trends* (Los Angeles, CA: Higher Education Research Institute, University of California at Los Angeles, 1987), pp. 14-19.

calaureate degrees granted. The number of natural science and engineering Ph.D.s awarded each year is small, between 12,000 and 14,000. Thus, programs that make the Ph.D. more attractive, or other factors leading to fluctuations in Ph.D. awards, can have sizable influence on the research work force.

OTA concludes that the changing demographics of the college-age population, including its racial and ethnic composition, are not necessarily predictive of either the size or quality of the future science and engineering talent pool. There are ways to increase participation of all kinds of students at each level of the American educational system. This system is more flexible and less predictable than the demographics suggest. Individual choices, affected by schools and the job market, can go far to meet society's future needs for scientists and engineers.

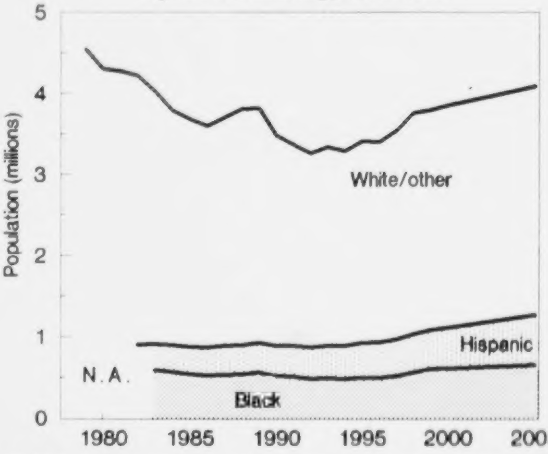
Should government intervention to increase the number of people equipped to do science or engineering be judged desirable, there is evidence to guide appropriate policy actions. This assessment summarizes the evidence and reviews policy options for creating an adequate future supply of scientists and engineers.

THE DEMOGRAPHIC OUTLOOK AND COMPOSITION OF THE TALENT POOL

Like many other professions in U.S. society, science and engineering have historically drawn their members from the white male segment of the population. Today, the total college-age population is shrinking while its minority component—which has never been well-represented in science and engineering—is growing. The size of the college-age population at the turn of the century can be estimated reliably, since they have already been born. Census Bureau projections show that the number of U.S.-born 18-year-olds will fall until the mid-1990s before recovering substantially in the succeeding decade. As seen in figure 1-1, some describe this pattern as a "roller coaster." At the same time, the minority proportion of each cohort will rise slowly but steadily. (See figure 1-2.) In absolute terms, the number of Black 18-year-olds is also falling, although not as rapidly as whites. The number of Hispanic youth is rising. By the year 2000, over 25 percent of the college-age population will be Black or Hispanic.[5]

A simple estimate of future scientists and engineers is obtained by multiplying the population of college-age people in the birth cohort by the historical proportion of college students, by sex and minority composition, who major in science or engineering. Similar formulas are thought to govern each birth cohort's participation in graduate school and the eventual yield of Ph.D. scientists and engineers. This sort of simple extrapolation predicts declining output of scientists and engineers, which some take as a portent of inevitable personnel shortages in certain fields of science and engineering.[6]

Figure 1-1.—Size of 18-Year-Old Population, by Race/Ethnicity, 1979-2005



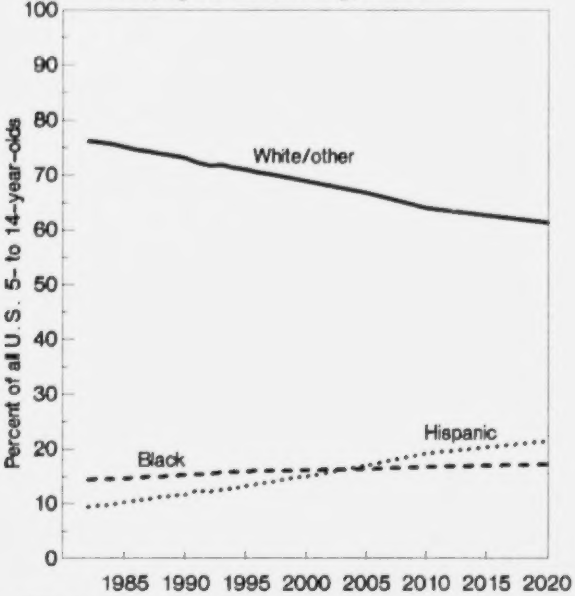
NOTE: Series 17 projections—middle fertility, middle mortality, high net immigration

SOURCE: U.S. Bureau of the Census, *Estimates of the Population of the United States by Age, Sex, and Race: 1980 to 1986*, Current Population Reports, Series P-25, No. 1000, *Projections of the Hispanic Population: 1983 to 2080*, Current Population Reports, Series P-25, No. 995, *Projections of the Population of the United States by Age, Sex, and Race: 1983 to 2080*, Current Population Reports, Series P-25, No. 952.

Harold L. Hodgkinson, *All One System: Demographics of Education, Kindergarten Through Graduate School* (Washington, DC: Institute for Educational Leadership, 1985). The increased number of non-Asian minorities will be concentrated in a few States such as California, Louisiana, Mississippi, New York, and Texas. There is also a public-private school difference: minority enrollment in public elementary and secondary schools nationwide is *currently* about 30 percent. The minority student population is much smaller in private schools.

[6] National Science Foundation, *The Science and Engineering Pipeline*, PRA Report 87-2 (Washington, DC: April 1987), pp. 1-2.

Figure 1-2.—Population Projections of 5- to 14-Year-Olds, by Race/Ethnicity, 1982-2020



NOTE: Series 17 projections—middle fertility, middle mortality, high net immigration.

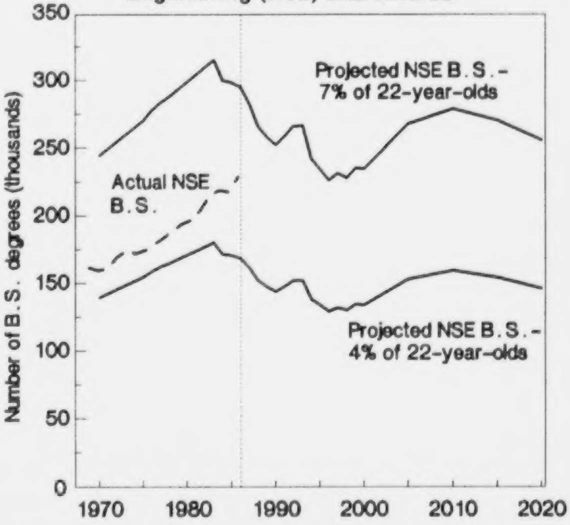
SOURCE: U.S. Bureau of the Census, *Projections of the Population of the United States, by Age, Sex, and Race: 1983 to 2080, Current Population Reports, Series P-25, No. 952; Projections of the Hispanic Population, 1983 to 2080, Current Population Reports, Series P-25, No. 995.*

The number of minority high school graduates, particularly Black males, who apply for and enroll in college has been declining for the last 5 years. Large high school dropout rates persist among Hispanics (only 60 to 70 percent of whom complete high school by age 24).[7] On the other hand, the Black and Hispanic communities are far from homogeneous. Life experiences of Blacks vary between the North and the South, and between rural and urban areas. The Black middle class is growing and, since educational success correlates more closely with social class than with race, Black participation rates may rise. The experiences of Hispanics vary considerably by their geographic origin: Mexican-American (Chicanos), Puerto Rican, and Cuban are the three origins on which data are sometimes reported.[8]

One cannot draw safe conclusions about future supplies of scientists and engineers on the basis of aggregate demographic trends alone (see figure 1-3). **It is important to disaggregate and examine how students of different talents, sexes, race, and ethnicity flow through the education system to determine how the talent pool for scientific and engineering careers is formed and how degree aspirations are realized.**

The future science and engineering work force begins with individual decisions to select and prepare for such a career. Among the factors that researchers cite as being important to this decision (summarized in table 1-1) are gender, race or ethnicity, parental occupations and other family influences, socioeconomic status, kind of school attended and courses taken, teaching practices employed, student's ability and talent, type of undergraduate college at-

Figure 1-3.—Projections of Natural Science/Engineering (NSE) B.S. Awards



NOTE: OTA projections of natural science/engineering degrees assume a range of 4 to 7 percent of 22-year-olds obtain B.S. degrees in natural science/engineering. The rate in 1986 was 5 percent (7.5 percent for all science/engineering); the average rate from 1975-85 has declined from 8 to 7 percent for science/engineering, and has ranged from 4 to 5 percent for natural science/engineering (Center for Education Statistics degree data and U.S. Bureau of the Census population data). Natural science/engineering does not include the social sciences.

SOURCE: U.S. Department of Education, Center for Education Statistics.

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[7] James R. Mingle, *Focus on Minorities: Trends in Higher Education Participation and Success* (Denver, CO: Education Commission of the States and the State Higher Education Executive Officers, July 1987); U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *The Condition of Education: A Statistical Report, 1987 Edition* (Washington, DC: 1987), pp. 26-28; U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987* (Washington, DC: 1987), table 72.

[8] For most comparisons of student intentions, enrollments, and degree-taking, data are not available at this level of detail. Typically, the analytical categories of Black and Hispanic must suffice.

Table 1-1.—Factors Associated With Students' Majoring in Science and Engineering

The most important factors that contribute to students majoring in science and engineering

Factor	Principal effect
Being in the academic track	Access to advanced courses and encouragement
Taking the most demanding science and mathematics courses	Preparation for college science or engineering major
Race and ethnicity—being white or Asian rather than Black or Hispanic	Cultural acceptance of science or engineering as a career
Sex—male rather than female	Cultural acceptance of science or engineering as a career; no childbearing/family conflicts with career
Family socioeconomic status—being able to afford college	Well-educated, school-oriented parents; access to good schools; information on negotiating the system
Parents—having a parent who is a scientist or engineer	Role model, early and substantial exposure to science as process
Early research participation	Early exposure to how science really works
Intrinsic interest—finding science enjoyable	Curiosity about mathematics and science courses
Having a good, enthusiastic science teacher and/or guidance counselor	Heightened student interest and achievement; positive attitudes toward science; college attendance
Participation in an intervention program	Development of interest, enthusiasm, self-esteem
Being in a science-intensive school	Access to courses, labs, peers, and teachers—a science environment

Factors that may contribute to students majoring in science and engineering

Factor	Likely principal effect
Having a well-qualified science teacher	More likely to be knowledgeable about science and communicate positive attitude
Meeting or observing a scientist or engineer, having a role model	Self-identification with science
Being taught using many science experiments ("hands-on" experience)	Heightened interest and knowledge of reality of science
Being in a school district with a science coordinator	School is likely to have better curricula and facilities

Factors about which there is little evidence of contribution

Factor	Effect if any
Being in summer science camp	Self-confidence and enthusiasm developed from science being a voluntary activity
Television (e.g., "3-2-1 Contact")	Heightened enthusiasm, self-concept, and knowledge about science
Science centers and museums	Alternative to classroom; "Explainer" experience builds academic self-esteem
National Science Foundation mathematics and science curricula	More experimental work, more relevant content
Having a teacher that has been through a National Science Foundation teacher institute	Teacher more interested in and knowledgeable about science
Having a good textbook	More likely to maintain interest in science classes
State and local graduation requirements	More likely to take more and higher level mathematics and science classes
Being in a school or district that benefits from Department of Education Title II funding	Better trained teachers, more equipment
Career seminars and brochures	Better knowledge of what science and engineering careers are about
Teacher salaries and school funding	Richer schools can afford to do more in science, get better teachers, and retain them

SOURCE: Office of Technology Assessment, 1988 tended, early participation in scientific research, and availability of graduate funding. While the probability that a woman, Black, or Hispanic will major in science or engineering is many times lower than that of a white male, it is not easy to express and measure exactly *what* it is about being female, a member of an ethnic minority, or a white male that leads to these behaviors.[9]

It is not necessary to understand all the causes of cultural, racial, ethnic, and sex differences that underlie the propensity to major in science and engineering before seeking to make changes to the system. It is helpful, however, to understand how coming demographic changes will translate into the passage of talent through the education system. Although the talent pool forms as early as junior high school, its composition evolves from students who are interested in science and mathematics in the early grades and attend college, to those who major in science or engineering and actually earn degrees in these fields.

THE SCIENCE AND ENGINEERING "PIPELINE"

The formal education system is seen by many as a kind of "pipeline" through which students pass on their way to science and engineering careers. The pipeline is a model of the process that refines abundant "crude" talent into select "finished" products as signified by award of baccalaureate, master's, and doctorate degrees (for an example, see figure 1-4). According to this model:

- "Although the talent pool seems to reach its maximum size before high school, migration into the pool continues to occur during grades 9 through 12. However, after high school, migration is almost entirely out of, not into, the pool."[10]
- "The early years (prior to 9th grade) are critical in recruiting students to the sciences. Socioeconomic status (parental educational attainment, occupation, and income) is a strong influence at this stage, affecting values and formal and informal educational activities that have a major impact on the development of children's interests and abilities."[11]
- "[In high school] the influence of aptitude and sense of competence are critical . . . . Particularly crucial are the decisions students make regarding enrollment in advanced mathematics courses."
- "Major losses to the science and engineering talent pool occur during the college years. This signals the need to pay more attention to the quality of undergraduate programs—the extent of interaction between students and senior faculty, the balance between curricula designed to weed students out and curricula designed to nurture students along, and the availability of undergraduate research experiences."
- "The transition from undergraduate to graduate school is another big loss point . . . . Students' perceptions of opportunity are key here. The availability of jobs, income potential, job security, and occupational status all come into play."

The pipeline model emphasizes the links between all stages of formal education, from kindergarten through graduate school. It suggests that an early display and recognition of talent is essential. Without the traditional preparatory mathematics and science courses, students are left behind, unable to catch up if they aspire to a scientific or engineering career. Yet losses of aspiring science and engineering students occur at each juncture in the pipeline. While an attitude of exclusivity has typified the cultivation of science and engineering talent, a broader base of learners has always been possible. The National Academy of Sciences concludes:

> Every educational and developmental stage is a potential point of intervention, and a comprehensive approach to nurturing science and engineering talent must address the whole pipeline.[12]

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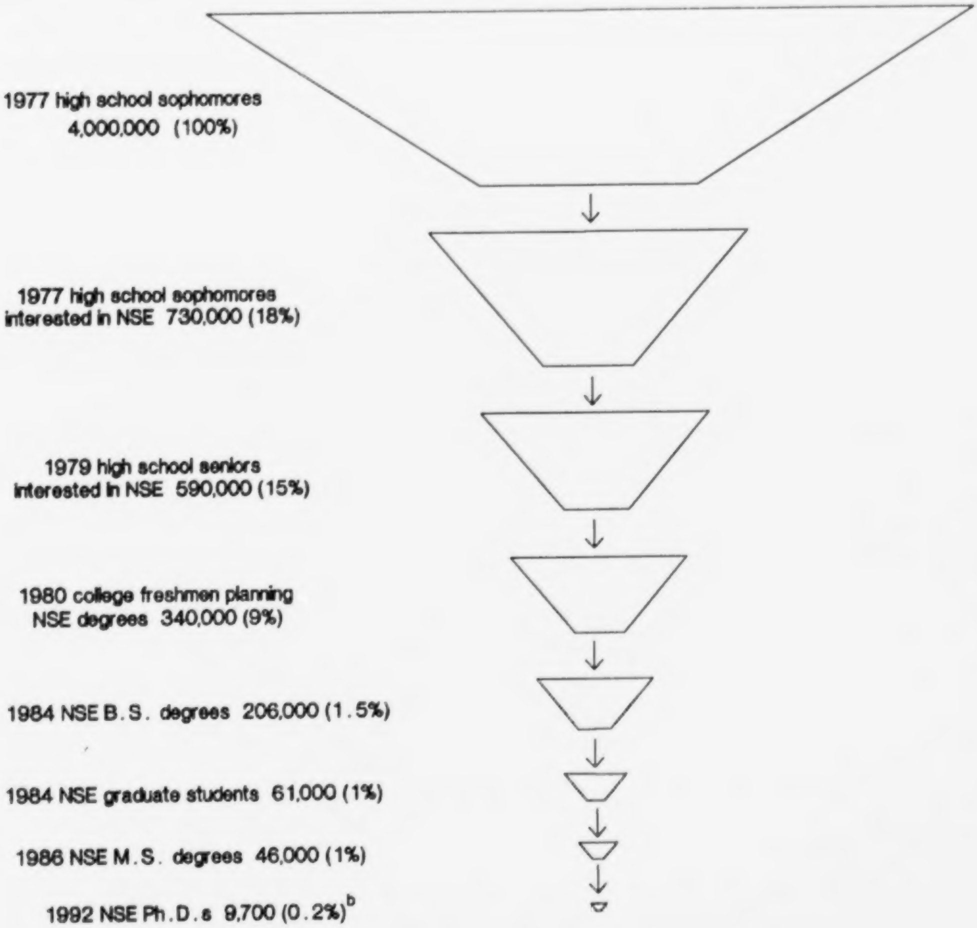
[9] The complexity of such questions of cause and effect is well described by a study of the causes of the national decline in achievement test scores, recently published by the Congressional Budget Office. U.S. Congress, Congressional Budget Office, *Educational Achievement: Explanations and Implications of Recent Trends* (Washington, DC: August 1987).

[10] Sue E. Berryman, *Who Will Do Science?* A Special Report (New York, NY: The Rockefeller Foundation, 1983), p. 7.

[11] Government-University-Industry Roundtable, *Nurturing Science and Engineering Talent* (Washington, DC: National Academy Press, 1987), p. v. Quotations below are from this source unless otherwise noted.

[12] Ibid.

Figure 1-4.—Natural Science/Engineering[a] Pipeline: Following a Class From High School Through Graduate School



[a] Natural science/engineering (NSE) includes physical, mathematical, and life sciences, and engineering, but not the social sciences.

[b] National Science Foundation estimate, based on the historical rate in NSE of 5 percent of B.S. graduates going on for Ph.D.s (using an 8-year average lag time from B.S. to Ph.D.). If market conditions increase demand for Ph.D.s, then this estimate may understate future production of NSE Ph.D.s. The number of NSE Ph.D.s in 1986 was about 12,000, or over 7 percent of NSE B.S. graduates in 1978 (Center for Education Statistics degree data). Assuming 7 percent of 1986 B.S. graduates rather than 5 percent go on for Ph.D.s would project 14,400 NSE Ph.D.s in 1992 rather than 9,700. Other methods of prediction (for instance, estimating Ph.D.s as a percent of the 30-year-old age cohort) show similar responsiveness to changing participation rates and assumptions. The Ph.D. population is very small and responds to changing conditions in academia and the job market, so that population-based estimates should be taken as rough indicators or warning signals rather than as solid predictions.

NOTE: These National Science Foundation estimates indicate the general pattern of the NSE pipeline, but are not actual numbers of students in the pipeline. (For instance, actual natural science/engineering B.S. production was 209,000 in 1986, Center for Education Statistics data.) The estimates are based on data from the U.S. Department of Education-sponsored National Longitudinal Study of 1972 Seniors (for the high school senior through graduate school transitions) and High School and Beyond Study of 1980 Seniors (for the high school sophomore to high school senior transition). Since the National Longitudinal Study was conducted, student interest in NSE majors has risen, but it is not yet clear whether trends in student interest with time will follow the pattern of 1972 high school seniors revealed by the National Longitudinal Study.

SOURCE: National Science Foundation, *The Science and Engineering Pipeline*, PRA Report 87-2, April 1987, p. 3; and personal communication with National Science Foundation staff.

Clarifying the Portrayal of Supply

In reality, each tier of education has to work with the students with which it is fed. In recent years, each tier has voiced serious complaints about the quality of students emerging from the preceding tier. Nevertheless, the task is to do the best with the available students rather than bemoaning the situation and laying blame.[13] **OTA finds that the pipeline is not filled solely by the determined core of committed students who display early promise, high achievement, and drive. Estimates suggest that one-quarter of those who eventually go on to major in science and engineering come from outside the academic (college-preparatory) curriculum track.**[14]

In the long run, the greatest influence on the size and quality of the science and engineering work force is elementary and secondary education, for it is the schools that interest and prepare, or fail to prepare, students with the necessary background in science and mathematics. Schools are asked to do many things for students, including inspiring an appreciation for knowledge and instilling good study habits for its pursuit. One of their tasks is identifying and sorting talent (the "college-bound") for college study, which targets students for certain careers. Schools, in effect, are purveyors and engineers of culture, as well as being gatekeepers to the professions. This duality is expressed in competing desires for both mass *and* elite education: schools are expected to arrange programs for the "gifted and talented" and programs to bootstrap the disadvantaged and learning disabled. Against these objectives, the challenge is to prevent mathematics and science education from being shortchanged.

Schools, therefore, can do a lot to prepare or inhibit students in science and engineering, through actions such as course offerings, curricula, testing, and tracking. Calls today for "technological literacy" echo the post-Sputnik battle cry that raised the level of mathematics and science consciousness—and content—in the schools. But the teaching of mathematics and science leaves much to be desired—content at the elementary level, pedagogical techniques in high school. The training of science teachers, with its emphasis on teaching methods, often fails to inculcate in future science teachers an understanding of and enthusiasm for science as a process of inquiry, and not just a bundle of facts.[15]

The pipeline model is still a black box of the educational process that acts upon students. It portrays the net effects of this process as a dwindling supply of talent, with its composition in flux, that has been sorted and guided toward future careers that require additional education. As an analytical tool, the pipeline illuminates choices and motivations both within students and schools. Each is future-oriented, anticipating a market that will match skills and interests to expected employment needs. Although the match is imperfect, the funding of these needs creates "demand."

Anticipating Future Demand for Scientists and Engineers

The health of the economy, technological changes, and shifting government priorities, which cannot be projected with any useful degree of accuracy, all affect future demand for scientists and engineers (see table 1-2). Historically, this demand has been rising, and many analysts expect that growth to continue; but growth will vary significantly from field to field. The complexity of analyzing changes in demand for the relatively small science and engineering work force confounds forecasts and increases

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[13] There is widespread disenchantment with the overall quality of elementary, secondary, and even higher education, which is perceived to be declining, while its cost is rising in real terms. See, for example, National Commission on Excellence in Education, *A Nation at Risk* (Washington, DC: April 1983); Carnegie Forum on Education and the Economy, *A Nation Prepared: Teachers for the 21st Century*, The Report of the Task Force on Teaching as a Profession (New York, NY: Carnegie Forum, May 1986); *The Chronicle of Higher Education*, "Text of Presidents' Open Letter Urging Colleges To Be Active in School Reform," vol. 34, No. 4, Sept. 23, 1987, p. A23.

[14] This estimate is based on an analysis of the High School and Beyond survey, class of 1982. Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, September 1987. Though variations in the preparation and paths to a career in science or engineering are not well-understood, a detailed analysis of the relationship between course-taking and intended college major is contained in Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, op. cit., footnote 3.

[15] Edward B. Harvey and Lorna R. Marsden, "Excellence and Equality: The Contradiction in Science Teaching in America," *Science Teaching: The Year in School Science 1985*, Audrey B. Champagne and Leslie E. Hornig (eds.) (Washington, DC: American Association for the Advancement of Science, 1986), pp. 126-147; Iris R. Weiss, "Pre- and In-Service Training, Roles of Various Actors, and Incentives to Quality Science Teaching," OTA workshop summary, September 1987.

Photo credits: John Jernegan, MESA Program (inset); The Science Museum of Virginia and Association of Science and Technology Centers

The future supply of scientists and engineers could be improved by many actions. In the long term, the number of minorities that enter these fields can only be increased if more attention is paid to elementary and secondary education, where the minority talent pool is unduly curtailed. Here, minority students participate in an intervention program at the Lawrence Hall of Science, California, which offers special courses designed to interest students in science. Highly able white students could also be encouraged toward science and engineering; many now opt for other careers, such as business, instead. In either case, the same techniques, such as hands-on experiments in science, help stimulate students' interest in, and understanding of, science.

uncertainty, especially at the level of individual fields.[16]

Federal actions, because of their pervasive effects on the economy and on the size and location of research and development (R&D) activities, have strong effects, both direct and indirect, on the demand. Spot shortages and surpluses in some disciplines seem unavoidable as long as we maintain a dynamic economy. Recent examples include certain computer-related engineering and science subfields, and resource geology before that. Market forces tend to correct such shortages before policy measures

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[16] Concern for and methods of projecting employment demand for scientists and engineers were reviewed in U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force—A Technical Memorandum*, OTA-TM-SET-35 (Washington, DC: U.S. Government Printing Office, December 1985), esp. ch. 3. OTA concluded first, that labor markets for scientists and engineers display considerable flexibility. These markets send signals to potential new entrants and to existing participants causing them to realign their education and training according to market needs. Second, trends toward increasing participation by women, older students, and minorities will push overall participation rates up, even as birth cohorts shrink.

Table 1-2.—Factors Influencing Demand for and Supply of Scientists and Engineers

Factors that increase demand
- Increase in basic research
- Increase in mission research
- Economic growth
- Increasing technological sophistication of U.S. manufacturing and services due to scientific progress, international competition, and demand for a higher standard of living
- Increase in science and engineering higher education enrollments (causing an increased demand for faculty)

Factors that decrease demand
- Sending R&D and engineering offshore
- Decrease in basic or mission research
- Economic recession

Factors that shift demand between disciplines
- Technological change and scientific advance of all kinds, which render some disciplines obsolete while creating new ones
- Automation of engineering functions by means of computer-aided design and manufacturing and other communication and information technologies
- Using technicians for some tasks now undertaken by scientists and engineers

Factors influencing supply
- The size and rate of increase or decrease of demand for scientists and engineers modulated by the salary advantage for scientists and engineers and the national level of R&D expenditure
- The number of births and their racial and ethnic composition
- Education at elementary, secondary, and higher levels
- Permanent and temporary immigration of foreign scientists and engineers
- Federal and State initiatives to encourage different types of institutions to award more science and engineering degrees or award degrees at a higher level
- Legislation and other actions that affect the opportunity to attend and afford college or graduate education

SOURCE: Office of Technology Assessment, 1988.

would.[17] Nevertheless, policy is needed to ensure a baseline capacity to adjust to market changes.

Historically, scientists and engineers have experienced lower unemployment than other professionals. Based on employer reports and salary offers to new graduates, at present, no long-term shortages are apparent.[18] Salaries are an indicator of demand; salary increases in a field or industry signal a need to attract more trained personnel, both new graduates and those elsewhere in the work force. For example, spot shortages in certain engineering specialties (such as those supporting the energy boom of the 1970s and the electronics boom of the early 1980s) occasionally drive salaries up rapidly before subsiding.[19]

When the number of students in the educational system (usually at the undergraduate level where enrollments indicate the likely future distribution of degrees):

> . . . is deemed too low in a given field, as compared with an anticipated need for their services, policymakers can deploy strategies designed to increase this number. Broadly speaking, these strategies seek to increase the percentage of students at that stage majoring in the shortage field or to reduce student attrition up to that stage. . . . It appears that strategies designed to reduce the attrition from natural sciences and engineering coursework are more realistically based than field-specific strategies.[20]

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[17] More pronounced shortages are created by Federal research missions, such as the Apollo program in the 1960s. See Arnold S. Levine, "The Apollo Program: Science and Engineering Personnel Demand Created by a Federal Research Mission," OTA contractor report, October 1986.

[18] National Science Foundation, *National Patterns of Science and Technology Resources*, NSF 86-309 (Washington, DC: 1986).

[19] Engineering salaries over the past 30 years have been flat, in real dollars. The most recent information on job offers to science and engineering graduates indicates that although salaries are not increasing—a sign of a steady supply—at all degree levels scientists and engineers enjoy the highest average starting salaries relative to other fields. Commission on Professionals in Science and Technology, *Salaries of Scientists, Engineers, and Technicians* (Washington, DC: October 1987). A primary source of salary data is the annual College Placement Council survey, which notes that average salary offers to women in 1987 were lower than to men in all fields except engineering (see *Manpower Comments*, September 1987, pp. 12-13).

[20] National Science Foundation, op. cit., footnote 6, p. 2.

STRATEGIES TO MEET FUTURE NEEDS: FEDERAL AND STATE ROLES

In articulating concern about future numbers of scientists and engineers, politicians and industry leaders have linked educational needs to improving the Nation's industrial competitiveness in a global economy. **Several strategies exist to hedge against shifting national needs and any enduring mismatches between increasing future demand for scientists and engineers and the supply that would result from unperturbed historical trends.** Strategies that emphasize the *supply* of talent must focus on education and the schools; therefore, the principal policy actors are Federal and State Governments. Various other institutions, however, have roles to play.

Strategies are of two general types: retaining students interested in a science or engineering career by reducing their attrition from the talent pool, and recruiting new students to enlarge the pool. One specific strategy is to encourage more students of the kind that have traditionally entered these careers, predominantly highly able white males, to shift from their current careers of choice (such as business) back to science and engineering fields. Another is to enthuse the vast majority of students who are now disaffected from science in elementary and secondary education for whatever reason—poor teaching, undemanding curricula, or belief that science and engineering are too difficult. Still another strategy is to provide more support to women and minorities to enter careers in science and engineering. There is now emerging, in particular, a considerable body of empirical knowledge on the things that can be done to encourage women and minorities to study science and engineering. Such actions include the introduction of role models, the use of intervention programs, familiarizing teachers with the subtle ways by which they discriminate by race and by gender, and creating a classroom climate of high expectations and self-esteem among students.[21]

The surest strategy of all, and one that the United States has employed since these lands were first colonized, is to welcome immigration of scientists and engineers. American science and engineering has reaped longstanding benefits from this ready resource. At the graduate level, this policy is being applied in the face of declines in the numbers of U.S. citizens entering graduate school. The chief U.S. worry is an over-reliance on foreign talent, though it is unclear how much is "too much."[22] There are also ways of reducing the demand for U.S. scientists and engineers, including reducing spending on basic and applied research, making more intensive use of technicians, or taking R&D overseas and thus using foreign scientists and engineers.

Federal Influence on the Production of Scientists and Engineers

Federal R&D initiatives—although not intended primarily as personnel development programs—shape the research job market, the availability of academic research funds (including research assistantships), and consequently, the demand for Ph.D.s. These effects are amplified by the private sector's job markets, too, when—as is often the case—Federal programs influence industry R&D decisions. Undergraduate enrollments also respond to other Federal initiatives: the GI bill led to increases (especially of male veterans returning home after World War II),[23] Title VI of the Civil Rights Act of 1964 boosted college attendance by minority students,[24] and Title IX of the 1972 Education Amendments increased the participation of women in higher education.[25]

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[21] Shirley M. Malcom, *Equity and Excellence: Compatible Goals*, An Assessment of Programs That Facilitate Increased Access and Achievement of Females and Minorities in K-12 Mathematics and Science Education (Washington, DC: Office of Opportunities in Science, American Association for the Advancement of Science, December 1984), esp. pp. 14-20.

[22] Importing talent is controversial and risky, since imports may disturb domestic labor markets and since concerns about "brain drains" to the United States are already causing some foreign governments to consider ways to stem the losses from their own talent pools and to repatriate their citizens. Some also cite the oral communication skills of foreign-born faculty and teaching assistants as a problem in undergraduate science and engineering education. See Elinor G. Barber and Robert P. Morgan, *The Impact of Foreign Graduate Students on U.S. Engineering Education* (New York, NY and St. Louis, MO: Institute of International Education and Center for Development Technology, Washington University, June 1987), pp. 69-79.

[23] The Korean and Vietnam wars did not; enrollment increases—which occurred more in 2- than 4-year institutions after Vietnam—were proportional to population growth. U.S. Department of Commerce, Bureau of the Census, *School Enrollment—Social and Economic Characteristics of Students: October 1976* (Washington, DC: February 1978), pp. 1-4.

The most demonstrably effective direct Federal investment in science and engineering education of Ph.D.s is the funding of graduate fellowships in specific fields of study. Though few in number, fellowships and traineeships help produce Ph.D.s and encourage students to shift their postdoctoral plans.[26] There are few timely solutions to shortages of specialized skills other than the versatility of those already in the work force. Fine-tuning the educational system to affect the future production of scientists and engineers to meet anticipated transient conditions of changing job markets is difficult. The lag times in the education system, especially for Ph.D. scientists, are long compared to the usual duration of shortages in particular employment markets.

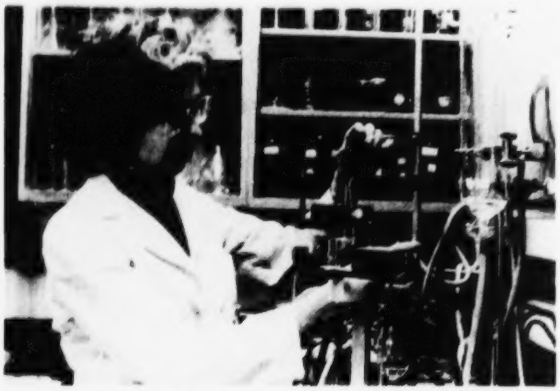

Photo credit: Carl Zitzmann, George Mason University

The Federal Government has a vital role in supporting the infrastructure of graduate science and engineering education in order to ensure an adequate supply of researchers. Federal support comes in several forms, recognizing the fundamental links, as well as the differences, between education and research at the graduate level. The principal forms are institutional support, research contracts, and fellowships and traineeships awarded to students. In seeking to maintain the educational infrastructure for science and engineering, Federal policy needs to address each of these forms.

A long-term program to increase the pool of potential scientific and engineering talent and the quality of those who eventually become scientists and engineers will have to tackle the schools as the principal institutions that motivate, attract, and deter students from various careers.[27] Other long-term measures might include:

- Federal support of special intervention programs to recruit and retain women and minorities in science and engineering (and eventually to institutionalize in the schools and colleges the interventions that work).
- Federal support for the propagation of higher education environments that are unusually productive of baccalaureates who eventually gain Ph.D.s in science and engineering. (These environments include not only research universities, but also others that excel at integrating teaching and research for particular populations: private liberal arts colleges, including a subset of predominantly women's colleges and traditionally Black institutions.[28])
- Focusing the responsibility for precollege mathematics and science (addressed to teachers and students alike), as well as undergraduate science and engineering programs, experiments, and evaluations, on the National Science Founda-

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[24] Meyer Weinberg, *The Search for Quality Integrated Education: Policy and Research on Minority Students in School and College* (Westport, CT: Greenwood Press, 1983), pp. 306-319.

[25] Phyllis Wei-Erh Cheng, University of Southern California, "The New Federalism and Women's Educational Equity," unpublished manuscript, December 1987.

[26] The postdoctoral fellowship is a multipurpose measure. For the recipient, it can be an award of distinction, a period for augmenting one's technical skills, and/or a way of postponing entry to a fallow market of, say, limited academic opportunity. Interpretations of postdoctorates as a post-Ph.D. status and activity must take into account both impacts on the work force and the individual career. See National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981); William Zumeta, "Anatomy of the Boom in Postdoctoral Appointments During the 1970s: Troubling Implications for Quality Science?" *Science, Technology, & Human Values*, vol. 9, No. 2, spring 1984, pp. 23-27.

[27] Families, peers, and out-of-school influences (e.g., churches and community organizations) interact with schools, teachers, and counselors to underscore (or undermine) the image of science and engineering in American culture. See Robert E. Fullilove, "Images of Science: Factors Affecting the Choice of Science as a Career," OTA contractor report, 1987. The contrast of these interactions in Japanese culture is explored in William K. Cummings, "International Comparison of Science and Engineering Work Force Policies: Japan," OTA contractor report, 1987.

[28] See, for example, M. Elizabeth Tidball, "Baccalaureate Origins of Recent Natural Science Doctorates," *Journal of Higher Education*, vol. 57, No. 6, November-December 1986, pp. 606-620; Gail E. Thomas, "Black Students in U.S. Graduate and Professional Schools in the 1980s: A National and Institutional Assessment," *Harvard Educational Review*, vol. 57, No. 3, August 1987, pp. 261-282.

tion's (NSF) Science and Engineering Education (SEE) Directorate.

Interaction of the States and the Federal Government

Although the Federal role in the national education system is old (through the Northwest Ordinance, it predates the U.S. Constitution), it is limited. Under the 10th Amendment to the U.S. Constitution, education is a power reserved to the States and the people and, as such, is taken very seriously by State legislatures and governments; it is the largest single item of State spending.[29] States, in turn, delegate their responsibilities for education to other bodies. In the case of elementary and secondary education, the provision and some of the funding of education are the charges of locally elected school districts, which hire their own teachers and staff and make many curricular decisions. Public university and college systems have extensive autonomy over higher education, but rely on States for funding.

Two Federal agencies, NSF and the Department of Education, specifically address science and engineering education. The mission agencies,[30] through R&D and a potpourri of programs, also contribute mightily. Under its enabling legislation, NSF is specifically charged with monitoring and maintaining the quality of the science and engineering work force. It is authorized and directed:

> . . . to initiate and support basic scientific research and programs to strengthen scientific research potential and science education programs at all levels in the mathematical, physical, medical, biological, engineering, social, and other sciences. . . .[31]

Even with the transfer of some functions to the Department of Education through later amendments and reauthorizations, the promotion of basic research and of education in science remains equal within the NSF mandate.[32] Until very recently, this mandate has been narrowly interpreted by the research community and the NSF leadership as mainly the provision of Federal basic research funds to the Nation's colleges and universities.[33]

The Department of Education is responsible for overseeing the general health of the entire national education system. It operates many major programs that, in fiscal year 1988, will provide $20 billion to States, school districts, colleges, and universities—approximately 6 to 7 percent of the national total spent on education.[34] Its charter calls for the collection of a huge variety of data, statistics, and research on education, and categorical support for students. The division of functions between NSF and the Department of Education is mirrored in Congress, where different committees have oversight and appropriations authority over research and education.

The overall Federal role in science and engineering education, exercised through NSF, the Department of Education, and the mission agencies, is most prominent at the undergraduate and graduate levels (see table 1-3). Graduate education relies heavily on Federal student, institutional, and research support. Financial aid programs, Federal research support, and the successive mounting and abandonment of research-intensive domestic and military programs influence the supply of and the demand for scientists and engineers. In particular, there is ample evidence that Ph.D.s, overall and in a given field, can be "bought" by offering fellowships, traineeships,

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[29] U.S. Department of Commerce, Bureau of the Census, *State Government Finances in 1985*, GF85-No. 3 (Washington, DC: December 1986).

[30] Mission agencies carry out the Federal responsibility in such areas as health, defense, space, energy, and agriculture. This division of labor corresponds to the Office of Management and Budget's categories in the Federal budget. The main research and development agencies are the National Institutes of Health, the Department of Defense, the National Aeronautics and Space Administration, the Department of Energy, and the U.S. Department of Agriculture.

[31] 180 U.S.C.A. (Ch. 16, National Science Foundation, Sec. 1862. Functions), 1987, p. 187.

[32] It is debatable whether an equal emphasis on research and education should translate into relatively equal dollars. Clearly, this has not been the case. In terms of outcomes, it is comparable to weighing the returns from investing a research fellowship in one Ph.D. candidate versus supporting a summer institute experience for three or four high school science teachers. The dollar equivalency will yield a measurable near-term effect on one student and his or her career, but an indirect, longer-term effect on perhaps untold numbers of students. Which is the better, or more effective, Federal investment?

[33] The emphasis of the current National Science Foundation leadership on centers and corporate participation in applications-oriented university-based research, in addition to individual investigator projects, is a clear break from the post-Vannevar Bush tradition. See Deborah Shapley and Rustum Roy, *Lost at the Frontier: U.S. Science and Technology Policy Adrift* (Philadelphia, PA: ISI Press, 1985), esp. chs. 1-3.

[34] U.S. Department of Education, *Digest of Education Statistics 1987*, op. cit., footnote 7, pp. 25, 263-267. (The percentage is based on data for fiscal year 1985.)

Table 1-3.—Major Federal Programs Affecting the Education of Future Scientists and Engineers

National Science Foundation ($100-$300 million)[a]
- K-12: teacher training, curriculum and materials development, informal education, research, recognition program for exemplary teachers, research participation for high school students
- Undergraduate: research participation, instrumentation, undergraduate creativity awards
- Graduate: graduate fellowships, graduate fellowships for minorities, research assistantships via research contracts, engineering fellowships

U.S. Department of Education ($200-$500 million)
- K-12: Title II, Education for Economic Security Act, used primarily for science and mathematics teacher training; magnet school grants (not specifically targeted to science and engineering); discretionary programs
- Undergraduate: Pell Grants (not specifically targeted to science and engineering), Minority Science Improvement Program, cooperative education (about 15-30 percent of cooperative students are in science and engineering)
- Graduate: Minority Institutions Science Improvement Program; Graduate and Professional Opportunities Program; Javits Predoctoral Fellowships

National Institutes of Health ($400-$500 million)
- K-12: research apprenticeships for minorities
- Undergraduate: Minority Access to Research Careers Program, Minority Biomedical Research Support
- Graduate: National Research Service Awards Predoctoral Training Grants, research assistantships funded via research contracts, National Institutes of Mental Health Minority Fellowships

Other agencies with substantial science education efforts

K-12
- U.S. Department of Agriculture: 4H, research apprenticeships
- U.S. Department of Defense: research apprenticeships at laboratories
- U.S. Department of Energy: Prefreshman Engineering Program, for women and minorities; student research apprenticeships and teacher training institutes at national laboratories
- National Aeronautics and Space Administration: research apprenticeships, teacher workshops, and resource centers

Undergraduate
- U.S. Department of Agriculture: Land Grant allocations (not specifically targeted to science and engineering)
- U.S. Department of Commerce: National Oceanic and Atmospheric Administration Sea Grant Program
- U.S. Department of Defense: Reserve Officer Training Corps (ROTC) (about 75 percent of funds are spent on science and engineering majors)
- U.S. Department of Energy: University-Laboratory Cooperative Program for summer research
- Department of Health and Human Services: Health Careers Opportunities Program

Graduate
- U.S. Department of Agriculture: Land Grant allocations (not specifically targeted to science and engineering)
- U.S. Department of Defense: research assistantships via research contracts, graduate fellowships
- U.S. Department of Energy: fellowships in particular research fields, summer research participation grants, research assistantships funded via research contracts
- U.S. Environmental Protection Agency: research assistantships via research contracts
- National Aeronautics and Space Administration: graduate fellowships, minority graduate fellowships, research assistantships via research contracts

[a] NOTE: Estimates of annual spending are from 1988. With the exception of those in the National Science Foundation, each of the programs listed here is funded at the level of at least $1 million per year. Institutional development programs are omitted.

SOURCE: Office of Technology Assessment, 1988.

and research assistantships, which lessen the burden of cost to students while offering them valuable apprenticeships as they progress toward the degree.[35] In the near term, this step is probably the most effective way to increase the output of Ph.D.s, who form the core of our research scientists and engineers. In the longer term, research support and a robust university infrastructure sustain the Nation's capacity to replenish the supply of scientists and engineers, so long as those entering college are both interested and prepared for these careers.

From the perspective of Congress, however, elementary and secondary education is at the same time the part of the system in greatest need of improvement and also the most removed from direct Federal influence. National Science Foundation funding for elementary and secondary mathematics and science education peaked in fiscal year 1964, but even then represented less than one-half of 1 percent of all spending on elementary and secondary education.[36] NSF programs have focused principally on curriculum development and teacher training. Since fiscal year 1984, budget support for mathematics and science education has grown conspicuously in response to congressional initiatives.[37]

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[35] Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need To Know* (Washington, DC: Association of American Universities, 1986); Michael T. Nettles, *Financial Aid and Minority Participation in Graduate Education*, A Research Report of the Minority Graduate Education Project (Princeton, NJ: Educational Testing Service, 1987).

NATIONAL NEEDS AND THE GOALS OF SCIENCE AND ENGINEERING EDUCATION

The national goal of maintaining and invigorating a science and engineering work force demands policy efforts on three fronts to create adequate numbers of well-prepared students available to serve as scientists and engineers. First, capable young people must be welcomed throughout the educational process. Second, their talents must be nurtured by elementary and secondary schools and institutions of higher education. Third, they must perceive employment opportunities that utilize their talents by providing fulfilling work.

The pool of potential talent needs to be large and versatile, whether or not there is reason to fear a future shortage of scientists and engineers. To the extent that the education system unduly limits the talent pool by prematurely shunting aside students or accepting society's gender, race, and class biases in its talent selection, it is acting out a self-fulfilling prophecy of demographic determinism. Using the past performance and interests of minority students in science and engineering to project an inevitable shortage in these fields, for example, is a counsel of despair. In conveying information about the ostensibly desirable social and intellectual characteristics of scientists and engineers, seasoned with the stereotypes and images that permeate American culture, the formal education system sorts many otherwise talented students out of the science and engineering pipeline.

It is clear that American schools, colleges, and universities have the capacity to provide enough qualified scientists and engineers to meet the Nation's needs. However, there is evidence that the system may not be working as well as it could. Our schools can learn to identify talent better and to nurture it with greater care. Our universities can take measures to attract and retain more talent in science and engineering. Students who now fall through the cracks can be better served—both by the formal system and by informal means. All of these approaches can lead to a larger, stronger pool of talent that reflects the variety of American society in serving its future technological needs.

The loss of a potential scientist or engineer to a career in another profession is still society's gain. We would hope that our education system would prepare students for careers that will be in demand. But the market is too unpredictable to target specific personnel needs, so the goal of education, including that for science and engineering, should be to prepare students for an uncertain future by imparting a range of skills. **This means that the skills of scientists and engineers must be both specialized enough to satisfy the demands of a stable market for science and engineering faculty and industrial researchers and general enough to qualify degree-holders for special opportunities that arise farther afield from their training but grow central to the national interest.**[38]

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[36] Michael S. Knapp et al., "Part Three: NSF's Investment History in K-12 Science Education," *Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation, Volume 2* (Menlo Park, CA: SRI International, June 1987); U.S. Department of Education, *Digest of Education Statistics 1987*, op. cit., footnote 7, p. 25.

[37] In a National Science Foundation budget totaling $1.7 billion in fiscal year 1988, the Science and Engineering Education Directorate increased by 40 percent to $139 million. Following the reinstatement of the Science and Engineering Education Directorate in 1982, funding for elementary and secondary programs has increased steadily from $3.8 million in fiscal year 1983 to an estimated $80 million to $85 million in fiscal year 1988.

[38] A dynamic economy will create such national needs and imbalances. The best preparation for them is a malleable stock of what some economists call "human capital." See Howard P. Tuckman, "The Supply of Scientists and Engineers in an Era of Institutional and Technological Change," *Policy Research and Analysis Workshop on an Agenda for Science Policy Research* (Washington, DC: National Science Foundation, Sept. 17, 1987).

Chapter 2

Elementary & Secondary Education: Shaping the Talent Pool

Photo credit: William Mills, Montgomery County Public Schools

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Chapter 2

Elementary and Secondary Education: Shaping the Talent Pool

KEY QUESTIONS

- What factors are associated with students' choices to major in science or engineering in college?
- What can schools do to interest, motivate, and prepare students for careers in science or engineering?
- What influences outside school have similar effects?
- What has prior Federal policy attempted to do and how successful has it been?

KEY FINDINGS

- Mathematics preparation, hands-on laboratory and field experience, research participation, teachers' high expectations, high-quality teaching, and placement in the academic curriculum track or in a science-intensive school are correlated with interest in majoring in science or engineering in college.
- Career interests and expectations are also shaped by out-of-school experiences. Families are critically important influences.
- Elementary and secondary education as a whole needs renovation; mathematics and science are but one part of it. That huge system resists reforms. There are few incentives for teachers and schools to give most students the academic preparation required for a science or engineering career.
- Intervention programs, based both in the community and in the schools, can enrich children's experiences with and attitudes toward mathematics and science. Informal education in museums, science centers, summer camps, and community facilities may help remove barriers to learning.

The future supply of scientists and engineers depends, in the final analysis, on how well schools, families, and communities encourage children to study science and engineering. Many more students could emerge from high school interested in science and engineering, with good preparation in mathematics and science, than now do so. It is not easy, though, to identify what factors encourage students to prepare for science and engineering careers, or what factors deter them. (An attempt is made in chapter 1, table 1-1.) Students need interest, ability, and preparation in science and mathematics; none of these alone is sufficient. Students' social and economic standing, cultural traditions, sex, race, and ethnicity in turn shape their interest in science and engineering, their access to courses, and future educational opportunities. Many schools could do better jobs of encouraging students, of both sexes and of all ethnic backgrounds, to prepare for science and engineering careers. Other informal experiences, such as science centers and museums, educational television, and summer research programs, can also help generate interest.

In general, family, friends, and the media shape students' attitudes about careers in science and engineering. Unsupportive parents and friends or negative stereotypes of science can dim students' visions of such careers more surely than boring textbooks or teachers.[1] Researchers have documented the images of science that young students hold by asking them for written descriptions or drawings of scientists (see box 2-A). These results speak eloquently of the formidable task confronting a culture in continuing need of new scientists and engineers.

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[1] Robert E. Fullilove, "Images of Science: Factors Affecting the Choice of Science as a Career," OTA contractor report, September 1987.

Box 2-A.—The Unchanging Image of the Scientist

Children's ideas about scientists have changed little over the past 30 years. In 1957, Mead and Métraux summarized the views of about 35,000 high school students, noting consistently shared characteristics, and then a division between a positive and negative image:[1]

Shared Image

> The scientist is a man who wears a white coat and works in a laboratory. He is elderly or middle aged and wears glasses. . . . He may be bald. He may wear a beard, may be unshaven and unkempt. He may be stooped and tired. . . . He is surrounded by equipment: test tubes, bunsen burners, flasks and bottles, a jungle gym of blown glass tubes and weird machines with dials. . . . He spends his days doing experiments. He pours chemicals from one test tube into another. . . . He experiments with plants and animals, cutting them apart, injecting serum into animals. . . .

Positive Image

> He is a very intelligent man—a genius. He has long years of expensive training. He is interested in his work and takes it seriously. He works for long hours in the laboratory, sometimes day and night, going without food and sleep. . . . He is prepared to work for years without getting results. One day he may straighten up and shout: "I've found it! I've found it!" . . . Through his work people will be healthier and live longer, they will have new and better products to make life easier and pleasanter at home, and our country will be protected from enemies abroad.

Negative Image

> The scientist is a brain. He spends his days indoors, sitting in a laboratory, pouring things from one test tube into another. His work is uninteresting, dull, monotonous, tedious, time consuming. . . . He may live in a cold water flat . . . . His work may be dangerous. Chemicals may explode. He may be hurt by radiation or may die. If he does medical research, he may bring home disease, or may use himself as a guinea pig, or may even accidentally kill someone. . . . He is so involved with his work that he doesn't know what is going on in the world. He has no other interests and neglects his body for his mind. . . . He has no social life, no other intellectual interests, no hobbies or relaxations. He bores his wife. . . . He brings home work and also bugs and creepy things.

(See page 42 for student drawings of scientists.)

Based on their analysis, Mead and Métraux suggested that the mass media should emphasize the real, human rewards of science, the enjoyment of group work, and how science works. Schools, they said, should:

- emphasize participation in the classroom rather than passive learning;
- emphasize group projects;
- teach science as immediately pertinent to human values, living things, and the natural world;
- teach mathematical principles much earlier;
- provide teachers who enjoy and are proficient in science;
- make sure that teaching and counseling encourage girls;
- de-emphasize the rare individual geniuses of science, such as Einstein, to make science more accessible to the average child and emphasize the individual sciences as broad fields of endeavor;
- avoid talking about "Science, Scientists, and The Scientific Method" as a whole, and rather, talk about individual fields and what different methods are; and
- emphasize life sciences, humans, and other living things to make science more immediate to children.

Children of the 1980s hold images of science and scientists that are essentially unchanged from those of the 1950s. In 1986, researchers at Harvard University's Educational Technology Center applied Mead and Métraux's methodology to another generation of potential scientists. They reported that:

> Most responses sounded familiar: scientists are nerds and science is important but boring. The students had little inkling of the day-to-day intellectual activities of scientists, of what experiments are for, or of the social nature of the scientific enterprise.[2]

Also in 1986, Cheryl Mason investigated the source of students' images, based on drawings of scientists made by children using a "Draw-A-Scientist Test."[3] Two representative examples are shown below. Most drawings portray the familiar stereotype: the scientist is an elderly male, wearing a white coat and glasses and performing dangerous experiments. Interviews with 14- and 15-year-olds revealed that most students had developed impressions of science and scientists through movies and cartoons ". . . which depicted scientists as mad, antisocial men."

Such images are potent and persistent. They enter into students' decisions about courses and careers. In part, these images reflect real characteristics of many scientists. To the extent that the stereotypes mask the diversity and ordinariness of many scientists, however, they may unduly deter children from pursuing science. Images are difficult to change. Teacher training is important; many students in Mason's study cited teachers' personalities and their teaching methods as reasons for not liking science. Other approaches include exposure to a diversity of real-life scientists through field trips, guest presentations, and cooperative education and research work experience. Mead and Métraux's prescription still holds.

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[1] The following are direct quotes from Margaret Mead and Rhoda Métraux, "Image of the Scientists Among High School Students," *Science*, vol. 126, Aug. 30, 1957, pp. 384-390.

[2] *Harvard Education Letter*, "Why Do Few Students Want to Become Scientists?" vol. 4, No. 1, January 1988, p. 6.

[3] Cheryl L. Mason, Purdue University, "Student Attitudes Toward Science and Science-Related Careers: An Investigation of the Efficacy of a High School Biology Teacher Intervention Program," unpublished doctoral dissertation, 1986.

SCHOOLS AND STUDENTS

Elementary and secondary education is a huge and varied enterprise in the United States, costing $170 billion per year, 4 percent of the gross national product. It uses 2.5 million teachers, takes place in more than 60,000 public and 40,000 private schools, and enrolls 45 million students. Public education takes place in 16,000 school districts and is the single greatest component of State spending. In 1984-85, States contributed about 49 percent of the cost of running public schools nationwide, while local authorities and the Federal Government provided 45 and 6 percent, respectively. It costs about $4,000 per year to educate a student.[2]

The quality of schools is crucial in determining the size and quality of the science and engineering talent pool. The tradition of local control, however, limits Federal influence over this stage in the preparation of potential scientists and engineers. The Constitution "reserves to the States and the people" many residual powers, including education. In turn, the States (except Hawaii) delegate this responsibility to localities. School districts and schools, within the general boundaries of State education standards, decide which mathematics and science courses will be offered. Teachers and guidance counselors, using standardized tests and individual judgments, decide which students will be encouraged to pursue courses leading to higher education in science or engineering and which, perhaps unwittingly, will be discouraged.

Many scientists and engineers say their career interest crystallized as early as elementary or junior high school, and most seem to make explicit choices before entry into high school. This has led to the widespread belief that future scientists and engineers select these majors early in life, then work hard and persist with their plans without considering other choices.[3] But new evidence suggests that many students' plans for their lives, as reflected in their intended college majors, change during high school.[4]

Preparing scientists and engineers is but one of many tasks that schools are asked to do. Instead of playing "talent scout" and encouraging those with the enthusiasm and ability to pursue science or engineering careers, schools too often see their function as culling out those who do not fit the traditional image of those destined for college and the professions by discouraging them from taking preparatory courses (including electives).[5] All capable students should feel welcome to study science and mathematics, not just those who believe they "need" such courses for their future careers.

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[2] U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987* (Washington, DC: May 1987), tables 3, 4, 5, 21, 59, and 93. Data are the most recent in each case, but are drawn from various years between 1980 and 1987.

[3] Historical evidence for this belief is collected in Bernice T. Eiduson and Linda Beckman (eds.), *Science as a Career Choice* (New York, NY: Russell Sage Foundation, 1973).

[4] Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, September 1987.

[5] For example, see Mary Budd Rowe, "Getting Chemistry Off the Killer Course List," *Journal of Chemical Education*, vol. 60, 1983, pp. 954-956.

School practices such as ability grouping or tracking are often applied too rigidly, restricting the preparation of students who would otherwise be capable of pursuing careers as scientists or engineers. Poor teaching, restricted course offerings, and dull or unrealistic mathematics and science curricula also discourage students. In many schools, students' coursework could be more wisely guided.[6]

In these ways, some American schools deprive able students of adequate preparation for science and engineering careers. The decentralized American school system resists change, so improvements are very difficult to propagate. Certainly, Federal policy options are limited in this sphere. State education standards are undergoing intense scrutiny and are being tightened.[7] Results will be slow to appear.[8]

Formal Mathematics and Science Education

Many aspects of elementary and secondary school education in mathematics and science, such as overrigid tracking, poor curricula, and inadequate teaching, limit all students' opportunities and encouragements to major in science and engineering in college. For example, it is widely acknowledged that practical science experiments undertaken by students are an effective teaching method (and that students like them), but their role in high school science classes has declined somewhat during the last decade: lectures and discussions are more common.[9]

Photo credit: William Mills, Montgomery County Public Schools

Lectures and discussions are the most common teaching technique employed in mathematics and science classes. Too often, students emerge bored and alienated from science.

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[6] Some argue that the democratic tradition of American education is sometimes observed most fully in the breach. The resulting lack of student preparation wastes talent. See P.A. Cusick, *The Egalitarian Ideal and the American High School* (New York, NY: Longman, 1983); Arthur G. Powell, *The Shopping Mall High School: Winners and Losers in the Educational Marketplace* (Boston, MA: Houghton Mifflin, 1985).

[7] Education Commission of the States, *Survey of State Initiatives to Improve Science and Mathematics Education* (Denver, CO: September 1987).

[8] There are some indicators of declining quality, particularly in achievement test scores. Data from the National Assessment of Educational Progress, a congressionally-mandated study of student achievement in several subject areas, for instance, show that the science achievement scores of 9-, 13-, and 17-year-old students have declined continuously since the first science assessment in 1969, although scores of 9- and 13-year-olds have risen somewhat since the mid-1970s. Mathematics achievement test scores of all age groups fell between 1972 and 1978, but, with the exception of 17-year-olds, these losses were recouped by 1982. See National Science Board, *Science Indicators: The 1985 Report* (Washington, DC: U.S. Government Printing Office, 1985), p. 125. The science assessments for 1969, 1972-73, and 1976-77 were conducted by the Education Commission of the States and are summarized in National Assessment of Educational Progress, *Three National Assessments of Science: Changes in Achievement, 1969-77* (Denver, CO: Education Commission of the States, June 1978). The science assessment for 1982 was, however, a special supplement conducted by the Science Assessment and Research Project at the University of Minnesota and was funded by the National Science Foundation (rather than the Department of Education). The assessment is summarized in Stacey J. Hueftle et al., *Images of Science: A Summary of Results From the 1981-82 National Assessment in Science* (Minneapolis, MN: Minnesota Research and Evaluation Center, 1983). For mathematics, see p. 126 of the National Science Board's *Science Indicators* (referenced above); National Assessment of Educational Progress, *The Third National Mathematics Assessment: Results, Trends, and Issues* (Denver, CO: Education Commission of the States, April 1983).

In addition, international comparisons—while difficult to interpret because of the great differences between the education systems of different nations—show that the achievement test scores of those U.S. students taking the traditional regimen of courses preparatory for science and engineering careers lag those of their peers in other developed nations, including Japan and Great Britain. See Curtis C. McKnight et al., *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co., January 1987), pp. 22-30; F. Joe Crosswhite et al., *Second International Mathematics Study: Summary Report for the United States* (Washington, DC: National Center for Education Statistics, May 1985), pp. 4, 51, 61-68, and 70-74; Willard J. Jacobson et al., *The Second IEA Science Study—U.S.*, revised edition (New York, NY: Teachers College, Columbia University, September 1987); Robert Rothman, "Foreigners Outpace American Students in Science," *Education Week*, Apr. 29, 1987, p. 7; Wayne Riddle, *Comparison of the Achievement of American Elementary and Secondary Pupils With Those Abroad—The Examinations Sponsored by the International Association for the Evaluation of Educational Achievement*, 86-683 EPW (Washington, DC: Library of Congress, Congressional Research Service, Nov. 27, 1984, updated June 30, 1986). Declines in laboratory work in schools have also been attributed, for example, to its high expense and concerns about safety and liability.

[9] Iris R. Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education* (Research Triangle Park, NC: Research Triangle Institute, November 1987), table 25, p. 49.

Table 2-1.—Comparison of Selected Mathematics and Science Course Offerings by School Grade Range, 1977 and 1985-86

	Percentage of schools offering course			
	Of all schools with at least grades 7-9[a]		Of all schools with at least grades 10-12[a]	
Course title	1977	1985-86	1977	1985-86
Mathematics:				
General mathematics, grade 9	36	33	59	64
General mathematics, grades 10-12	17	42	46	
Algebra, 1st year	—	57	—	99
Algebra, 2d year	—	36	—	92
Geometry	33	41	97	95
Trigonometry	14	23	54	59
Probability/statistics	3	6	7	14
Advanced senior mathematics, with no calculus	—	12	—	36
Advanced senior mathematics, with calculus	—	12	—	34
Calculus	7	14	31	31
Advanced placement calculus	—	6	—	18
Science:				
Life science	22	57	18	46
Earth science	28	57	37	52
Physical science	23	53	40	68
General science, grade 7	65	43	23	25
General science, grade 8	57	41	26	26
General science, grade 9	21	17	46	31
General science, grades 10-12	6	6	11	18
Biology, 1st year	30	41	95	99
Chemistry, 1st year	23	34	89	91
Physics, 1st year	22	32	78	81
Biology, 2d year	—	17	—	53
Chemistry, 2d year	—	10	—	28
Physics, 2d year	—	4	—	11

[a] These schools may also contain higher or lower grades, respectively, but must at minimum cover the grade range specified.

SOURCE: Iris R. Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education* (Research Triangle Park, NC: Research Triangle Institute, November 1987), tables 4 and 5.

In the Nation's schools, offerings of mathematics and science courses vary widely.[10] Many offer less than full ranges of college preparatory courses in mathematics and the sciences and a few have only very limited offerings. For example, data indicate that 81 percent offer at least 1 year of physics, but only 31 percent of high schools offer calculus (see table 2-1). There are also significant geographical differences in mathematics and science course offerings: schools in the West and Mountain States tend to offer fewer science and mathematics courses than those in other regions of the country, and rural schools offer fewer than urban ones.[11] The number and range of mathematics and science courses offered by schools, however, increased somewhat between 1977 and 1985-86.[12]

Even when such courses are offered, enrollments are very low. Findings from a survey of 1982 high school graduates (the best available data on the courses that students actually take) suggested that less than 12 percent of students to whom calculus was offered, and less than 20 percent to whom physics was offered, took these courses.[13] The net effect is that few high school graduates have these course experiences. In 1982, 24 percent of high school graduates had taken chemistry, 11 percent physics, 7 percent trigonometry, and 6 percent calculus.[14] If more schools offered more college preparatory courses, enrollments in science and engineering would be expected to rise; increasing enrollments in existing courses is equally desirable.

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[10] Data about course offerings and takings are very difficult to interpret because there is little consistency among analysts about the classification system to use in aggregating the huge variety of course titles that exist in schools. In addition, there is no guarantee that two courses of the same name have similar content.

[11] National Center for Education Statistics, "Science and Mathematics Education in American High Schools: Results From the High School and Beyond Study," bulletin, May 1984, pp. 16-21; Weiss, op. cit., footnote 9, table 6, p. 23.

[12] Weiss, op. cit., footnote 9, table 5, p. 21.

Then there is the matter of course content. Some mathematics and science teachers cite the inadequacies of textbooks and concern about curricula in general.[15] In the 1960s, several efforts, many quite successful and federally funded, produced new classroom materials, especially in the sciences.[16] Less attention was paid to mathematics, however.

Now mathematics educators are pressing for better mathematics curricula and teaching. The mathematics research community, too, has been vigorous in its effort to reform the system of elementary, secondary, and undergraduate teaching of mathematics in the United States. The Mathematical Sciences Education Board was established under the auspices of the National Research Council in October 1985 to bring together mathematicians, mathematics educators, and representatives of school systems and local communities. The Board seeks to increase public understanding of school mathematics issues, formulate national goals for future mathematics teaching and learning, and plan ways to help States and school districts improve their curricula and performance in mathematics.

Photo credit: William Mills, Montgomery County Public Schools

Skilled mathematics and science teachers, especially in physics, are in short supply. Often, teachers qualified in other science or mathematics subjects are asked to teach such courses "out of field." Alternatively, schools may drop such courses altogether from their curricula.

The Quality of Teaching

Teachers are critically important. Good ones can excite interest and promote both comprehension and perseverence; bad ones can stifle enthusiasm and mystify students. There are many very good teachers in American schools, but also many poor ones. The challenge is to attract good people to teaching, then provide the support to make them effective teachers who want to stay in the profession.

Some school districts find it difficult to recruit enough science and mathematics teachers. Most have difficulty finding high-quality teachers, especially for subjects such as physics. Consequently, many science and mathematics teachers must teach more than one subject, or what is known as "out of field" teaching. The underlying problem is the quality of teacher training. Most educators think the training that new science and mathematics teachers receive before beginning to teach should be improved.[17] For example, elementary school teachers take little or no coursework in science and mathematics, yet are often expected to teach these subjects. In contrast, secondary school teachers often take respectable numbers of courses in science or mathematics, but these courses give them inaccurate images of what scientists do. Most of their science courses do not give them this information. Teachers strive to impart to students as much "content" as possible, neglecting time-consuming laboratory work and exercises in higher order thinking (which convey more of the reality of scientific work) in favor of lectures and tests of recall. There is very little consensus on what an improved college curriculum for future mathematics and science teachers should consist of, and little research is being conducted on this issue.

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[13] Evaluation Technologies Inc., *A Trend Study of High School Offerings and Enrollments: 1972-73 and 1981-82*, NCES 84-224 (Washington, DC: National Center for Education Statistics, December 1984), table 2.

[14] National Center for Education Statistics, op. cit, footnote 11, pp. 16-21.

[15] Audrey B. Champagne and Leslie E. Hornig, "Critical Questions and Tentative Answers for the School Science Curriculum," *The Science Curriculum: The Report of the 1986 National Forum for School Science*, Audrey B. Champagne and Leslie E. Hornig (eds.) (Washington, DC: American Association for the Advancement of Science, 1987), pp. 6-7.

[16] A comprehensive analysis of 81 different evaluation studies is reported in James A. Shymansky et al., "A Reassessment of the Effects of 60s Science Curricula on Student Performance," final report, mimeo, n.d. (a reworking of material originally published in 1983). This study found that, compared to control groups, students taking new curricula scored slightly higher on achievement tests, had more positive attitudes towards science, and exhibited smaller differences between the sexes in each of these attributes. Students taught by teachers who had been through preparatory teacher institutes scored higher than their peers taking the new curricula without this benefit. Patricia E. Blosser, "What Research Says: Research Related to Instructional Materials for Science," *School Science and Mathematics*, vol. 86, No. 6, October 1986, pp. 513-517; Ted Bredderman, "Effects of Activity-Based Elementary Science on Student Outcomes: A Quantitative Analysis," *Review of Educational Research*, vol. 53, No. 4, winter 1983, pp. 499-518.

[17] Iris R. Weiss, "Pre- and Inservice Training, Roles of Various Actors, and Incentives to Quality Science Teaching," OTA workshop summary, September 1987.

Mathematics and science teachers also need so-called inservice education to remedy gaps in their prior training and to update and broaden their knowledge. Table 2-2 lists current needs in inservice education. Although the amount of inservice education being offered by school districts is rising, it is still small. Anecdotal evidence suggests that, when such education is voluntary, only the most enthusiastic teachers (and presumably the best) participate, while those who need help the most are not reached. The Federal Government supports inservice education of teachers through the Department of Education and the National Science Foundation (NSF), but this funding has scattered impact.[18]

Training is only part of the picture. The whole environment in which teachers work constrains their enthusiasm. For example, systems of accountability, including teacher competency tests and checks on learning from lesson to lesson established by many States and school districts in recent years, may do more harm than good. By prescribing highly detailed lists of "objectives," course by course, school districts rob teachers of their professionalism by straitjacketing them into routines.[19] Given the

Table 2-2.—Inservice Needs of Mathematics and Science Teachers

- Remedies for inadequacies of existing teacher training programs.
- Updating of knowledge of developments in science and technology, and their uses.
- Improved understanding of generally applicable pedagogical techniques and those that reinforce equitable teaching practices.
- Updating of knowledge of teaching techniques that particularly apply to mathematics and science teaching.
- Updating of knowledge on effectiveness of and techniques for implementing developments in educational technology, such as computers, video, and CD-ROM.
- Opportunity to practice new teaching techniques and to share experiences with other teachers.

SOURCE: Office of Technology Assessment, 1988.

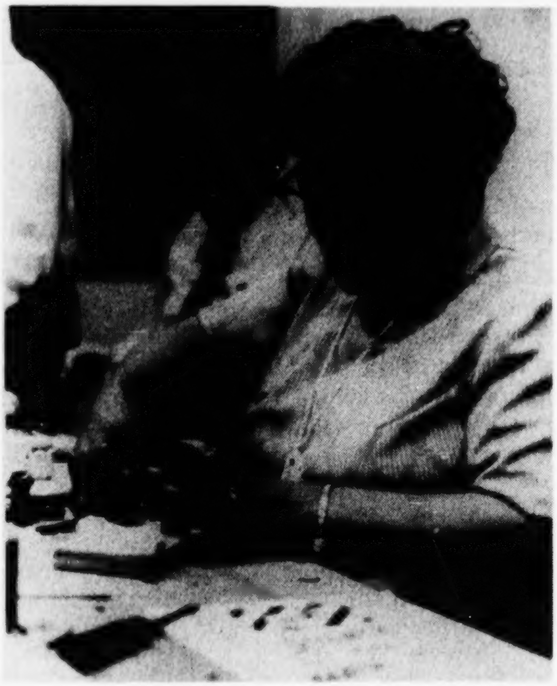

Photo credit: Lawrence Hall of Science

Teacher training (for those already certified and in the classroom) is conducted and funded by the States, school districts, foundations, industry, the Federal Government, and often by the teachers themselves. Still, many teachers either cannot or will not participate in such programs. Many successful science and mathematics teacher training programs are conducted at science centers and museums. Special emphasis is placed on hands-on experiments; this teacher is learning how one of these experiments works at the Lawrence Hall of Science, California, a science center that trains about 12,000 teachers per year.

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[18] The Federal Government spends about $110 million to $150 million per year (via Title II of the Education for Economic Security Act and the Teacher Preparation and Enhancement Program of the National Science Foundation's Science and Engineering Education Directorate) on teacher training. For details of the Title II program, see Ellen L. Marks, *Title II of the Education for Economic Security Act: An Analysis of First-Year Operations* (Washington, DC: Policy Studies Associates, October 1986).

[19] Weiss, op. cit., footnote 17.

Photo credit: Katherine Lambert, National Science Teachers Association

The Presidential Awards for Excellence in Science and Mathematics Teaching, a program administered by the National Science Foundation and managed by the National Science Teachers Association, was established in 1983 to recognize outstanding public and private school teachers in all 50 States who can serve as models for their colleagues in science and mathematics teaching.

poor quality of some curricula, such as those for mathematics, course specifications may be a necessary evil, however.

In addition, the image of teaching in the United States could be better. This image is reinforced by modest salaries compared to those science and engineering graduates earn in industry and government. Salaries have risen by about 25 percent in real terms during the last 5 years, and States and taxpayers are beginning to demand evidence of the positive effects of such increases. Qualified mathematics and science teachers are urgently needed, especially as role models for the growing minority student population.[20] Once in the classroom, excellent teachers must be retained. A number of ways of raising teachers' status and confidence could be tried. For example, teachers might be given increased opportunities for professional growth through short- or long-term sabbaticals and attendance at professional meetings, more time for class planning and less for noneducational duties (such as lunchroom supervision), and occasions to exchange ideas with other teachers via conferences and teacher centers (in their own schools and outside).[21]

Tracking and Ability Grouping

Nearly universal in American schools, the practice of ability grouping—particularly in the form of curriculum "tracking"—is intended to make efficient use of teaching resources and allow students to move through curricula at rates appropriate to their abilities and interests. However, such grouping also has powerful disadvantages. Some suggest that students' assignment to tracks is often highly related to their race, ethnicity, and socioeconomic status, rather than to their ability per se.[22]

Grouping by ability in subjects such as reading and mathematics begins as early as third grade.[23] It is continued to high school, where students are generally distributed among academic (college preparatory), general, and vocational curriculum tracks; at this level, movement between tracks rarely occurs. But there is some evidence that the stranglehold of tracking is loosening: more students than ever are in the general track and not the academic track, while the pattern of courses that students take shows that they are increasingly mixing high-level mathematics courses with formerly vocational courses.[24]

When too rigidly applied, tracking can reduce opportunity by restricting access to advanced preparatory courses in mathematics and science. Despite the fact that students in the academic track are more likely to take these advanced courses than are their peers in the general and vocational tracks, 25 percent of college sophomores in 1984 who planned to major in natural science or engineering had been in these nonacademic tracks in high school.[25] While tracking can be useful in schools, it should not be used as an excuse for directing students away from courses they have the ability to master. Advanced mathematics and science courses are within the reach of more young Americans than currently take them.[26]

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[20] Shirley M. McBay, *Increasing the Number and Quality of Minority Science and Mathematics Teachers* (New York, NY : Carnegie Forum on Education and the Economy, Task Force on Teaching as a Profession, January 1986).

[21] For a collection of perspectives, see *Educational Policy*, Special Issue on The Crisis in Teaching, vol. 1, No. 1, 1987, pp. 3-157. In October 1986, the 50,000-member National Science Teachers Association launched a teacher certification program. Early application requests suggest that there will be a huge response. The program is also aimed at influencing preservice teacher training. The National Council for Accreditation of Teacher Education is using National Science Teachers Association standards in accrediting science teaching programs in colleges and universities. See John Walsh, "Teacher Certification Program Under Way," *Science*, vol. 235, Feb. 20, 1987, pp. 838-839.

[22] Fullilove, op. cit., footnote 1; Jeannie Oakes, "Tracking: Can Schools Take a Different Route?" *NEA Today*, Special Issue, January 1988, pp. 41-47.

[23] Robert E. Slavin, "Ability Grouping and Student Achievement in Elementary Schools: A Best-Evidence Synthesis," U.S. Department of Education, Office of Educational Research and Improvement, Grant No. OERI-G-86-0006, June 1986.

[24] Evaluation Technologies Inc., *High School and Beyond: An Analysis of Course-Taking Patterns in Secondary Schools as Related to Student Characteristics* (Washington, DC: U.S. Department of Education, National Center for Education Statistics, March 1985).

Special School Environments

The ultimate extension of tracking and the demonstration of its potential benefits are schools that specialize in science and mathematics. There are three types of such schools:

- schools founded in the first part of the century when high schools were still a comparative rarity (such as the Bronx High School of Science in New York City);
- statewide schools (such as the School of Mathematics and Science in Durham, North Carolina); and
- magnet schools, which, although designed primarily to promote racial desegregation, can make important contributions to science education in cases of schools that take science and mathematics as their themes.[27]

These schools are often thought to be successful at winning converts to science and engineering careers, but there are no data to support or refute this contention; although many alumni do go on to science careers, it is to be expected that the students who enter such schools are more interested in science and mathematics than most. These schools are generally very popular with teachers and students, and are often oversubscribed. They are probably up to two or three times as expensive to operate as conventional schools.

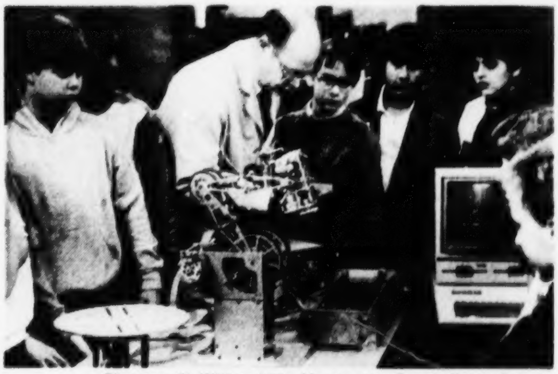

Photo credit: William Mills, Montgomery County Public Schools

Magnet schools, science-intensive schools, and other special school programs can give children the chance to work with sophisticated scientific equipment and topics. These programs can effectively stimulate interest in science and mathematics. However, schools and parents need to ensure that all students, regardless of sex, race, ability, or track, are given the opportunity and encouragement to explore science.

Issues similar to those raised by tracking are raised by special science schools. These issues include the possible draining of student and teaching talent from regular schools, and the diminution of curricular opportunities at regular schools. Whether special science schools have harmful effects seems to depend most on the specific political and organizational aspects of their implementation in each community. Some programs have been very controversial and have not done well, while others have been great successes. Almost always, the added choice given to parents and children by the opportunity to enroll in special science schools encourages communities to think about what they want from public education and to seek improvements from it.[28]

Magnet schools that specialize in mathematics and science also show some promising results for minority students. But since such schools are commonly designed to bring majority children into schools that are predominantly Black, sometimes minority children are more likely to be denied access to them, due to oversubscription, than are majority children. Apart from the desegregation rationale, elements of successful magnet schools could be replicated in schools of all kinds. Like all special school environments, magnets demonstrate the value of choice and diversity in American elementary and secondary education.

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[25] Lee, op. cit., footnote 4.

[26] Calculus, in particular, has been hailed as the springboard to acquiring the analytical tools needed for success in a host of fields. Lynn A. Steen (ed.), *Calculus for a New Century: A Pump, Not a Filter* (Washington, DC: Mathematical Association of America, 1988). The number of calculus courses offered, in particular, is rising rapidly. But trigonometry and math analysis are the "priming courses" for the calculus "pump."

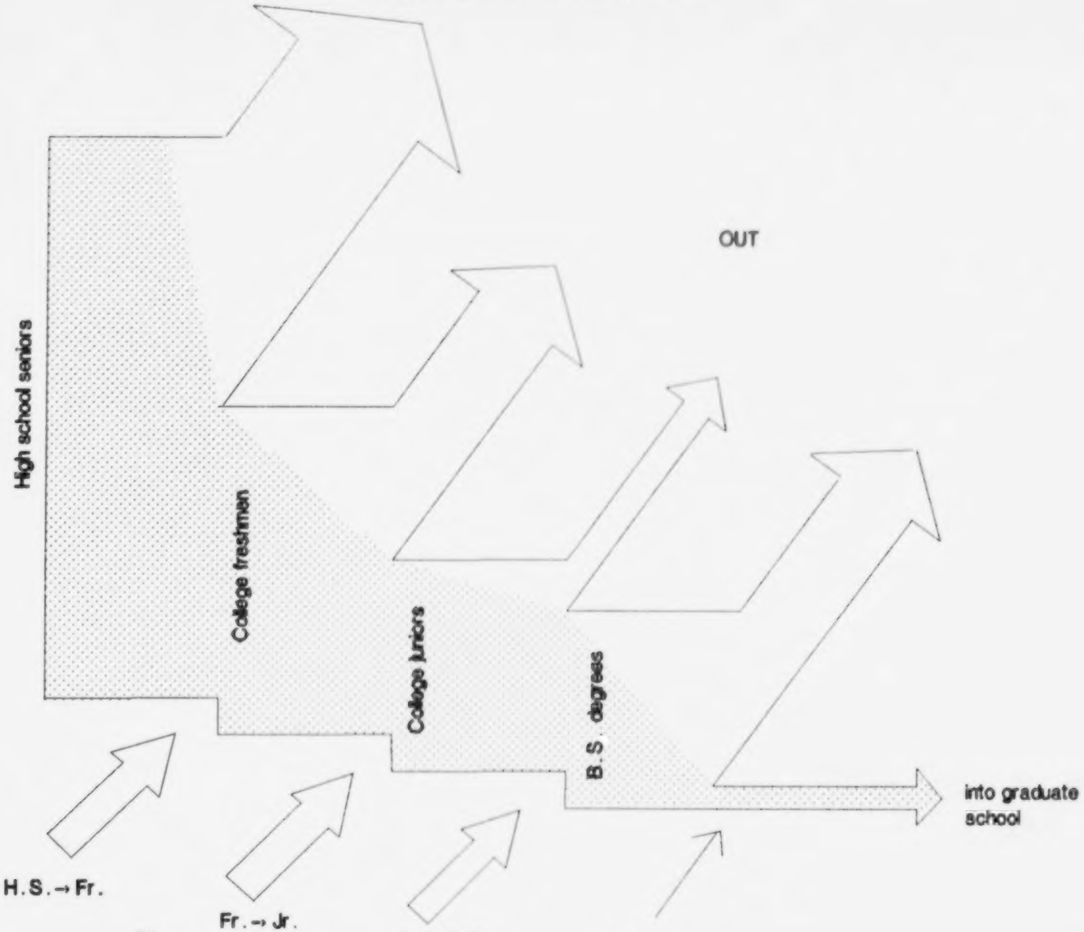
[27] There are in excess of 1,000 magnet schools at the moment, and their number is increasing. Probably about 25 percent of them adopt a mathematics or science theme. The most recent survey dates from 1983; Rolf K. Blank et al., *Survey of Magnet Schools: Analyzing a Model for Quality Integrated Education* (Washington, DC: James H. Lowry & Associates, September 1983.)

[28] Ibid.; *Education Week*, "Call for Choice: Competition in the Educational Marketplace," vol. 6, No. 39, June 24, 1987.

Student Career Plans

Although schools, families, and friends help determine students' career plans, such plans are, for most students, fairly volatile. As students are ex-

Figure 2-1.–Student Flows Into and Out of the Natural Science/Engineering Pipeline: The High School Senior Class of 1972



NOTE: Natural science/engineering includes physical, mathematical, and life sciences, and engineering, but not the social sciences. The width of the arrows reflects the number of students entering and leaving natural science/engineering at each stage. Among the 1972 high school seniors that plan to and do attend college, 13 percent are interested in natural science/engineering majors. Of this same college-bound cohort, by the first year of college 7.4 percent are interested in natural science/engineering; by college junior year, 4.8 percent; at college graduation, 4.6 percent; and only 0.8 percent enter graduate school in natural science/engineering.

SOURCE: Valerie E. Lee and Thomas L. Hilton, "Student Interest and Persistence in Science: Changes in the Educational Pipeline in the Last Decade," preprint, Feb. 10, 1987.

posed to new ideas, teachers, and experiences, their thoughts turn to the future and particularly the connection between education and employment. Students planning to attend college take a variety of courses and are often well prepared for a number of different majors. According to most observers, the pool of students planning science or engineering majors is well formed by entry to high school, and only erodes thereafter. This is misleading. New evidence suggests that students join this pool, even up to their sophomore year in college (see figure 2-1).

At present, the number of college freshmen planning careers in science and engineering is declining even though overall freshman enrollment is holding steady. Although most universities are not yet complaining of "shortages," student interest in science and engineering is waning, and interest in the physical sciences, mathematics, and engineering is falling faster than that in life and social sciences. There are also indications that a smaller proportion of the students with "A" or "A-" high school grade point averages ("high-achievers") now go on to major in science or engineering than in the past; many choose careers in business or law instead.[29]

To study how the science and engineering talent pool develops, OTA analyzed data from the U.S. Department of Education's "High School and Beyond" (HS&B) survey, which monitors two nationally representative samples, one drawn from those who in 1980 were high school sophomores. The survey contacts the same students every 2 years to collect data about their careers and educational progress.[30]

These students demonstrated considerable fluidity in their intended college majors as they progressed through the educational system. More than half of those interested in science and engineering as high school sophomores subsequently shifted to other subjects by their senior year. Others who had not named such majors as high school sophomores or seniors, in fact, were pursuing these majors as college sophomores. About 40 percent of these college sophomores planning science and engineering majors had indicated interest in nonscience majors when they were high school seniors.[31]

While most college sophomores intending to pursue science and engineering have above-average high school achievement test scores, about 20 percent do not. Furthermore, about 25 percent of these sophomores were enrolled in the general and vocational (rather than the academic) curriculum tracks in high school (see figure 2-2). Those who switch preferences in favor of science and engineering have slightly lower average achievement test scores and have taken fewer mathematics and science courses than those who persist in interest in science and engineering. They are also more likely to be females and members of ethnic or racial minorities.

As many as 25 percent of all high school graduates, but only 15 percent of college sophomores, are interested in majoring in natural science and engineering. Among these fields, in both the sophomore and senior years of high school, the life and health sciences (which includes medicine and health careers) are the most popular, followed by engineering. A tiny number of students plan majors in the physical sciences and mathematics.

Smaller proportions of Blacks and Hispanics than whites are interested in science and engineering majors. But in fields such as medicine and health, the proportion of Blacks and Hispanics who say they are interested in these majors is similar to that of whites. There are prominent gender differences; more women than men favor the life and health sciences, while men dominate the group interested in engineering, the physical sciences, and mathematics.

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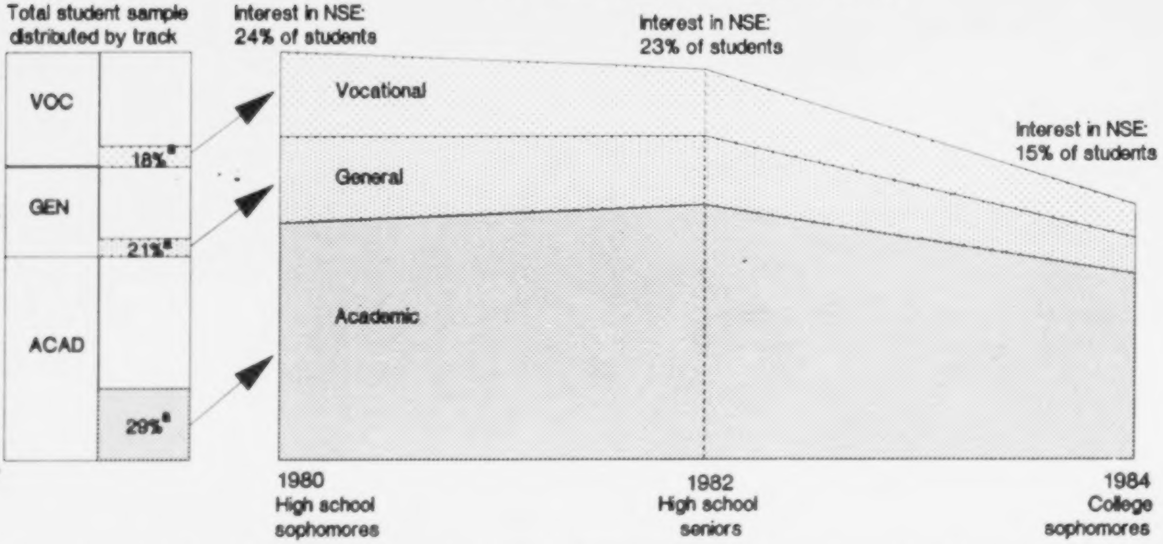
[29] Kenneth C. Green, "Freshman Intentions and Science/Engineering Careers: A Longitudinal Analysis Based on the CIRP Freshman and Follow-Up Data," OTA contractor report, December 1987. Trends in students' career plans are discussed further in ch. 3.

[30] Of the two cohorts in the High School and Beyond survey, OTA chose the high school sophomores of 1980 for analysis of influences (during the final 2 years of high school) on students' orientation to science and engineering. The most recent followup data available to OTA were from 1984, at which stage many students in this sample were college sophomores. It is possible, therefore, that those interested in science and engineering did not ultimately complete baccalaureate programs. Data from the 1986 followup, which will allow analysis of the numbers of students in this cohort that actually persisted to college graduation in science and engineering, were released after conclusion of this analysis. See Lee, op. cit., footnote 4. Based on previous longitudinal analyses, it is likely that the majority of those who expressed interest in science in their college sophomore year did indeed go through with their plans. Still, attrition of students between college sophomore and senior years is significant.

[31] These and other findings reported below are based on Lee, op. cit., footnote 4. Some aspects of them are confirmed in independent analysis of the same data by Theodore C. Wagenaar, *Occupational Aspirations and Intended Field of Study in College*, NCES 84-217 (Washington, DC: National Center for Education Statistics, November 1984).

Figure 2-2. - Interest of College-Bound Students in Natural Science/Engineering, by Curriculum Track: 1982 High School Seniors



aPercent of students in that track (who have not ruled out attending college) who are interested in natural science/engineering majors. Natural science/engineering does not include the social sciences.

NOTE: Overall, interest in natural science/engineering majors declines with time (24% of students in 1980, but only 15% in 1984 are interested in NSE). Students in the academic track are most likely to be interested in natural science/engineering majors and more likely to persist with their interest. At high school sophomore year, 60 percent of students interested in natural science/engineering majors were in the academic track; by sophomore year of college 74 percent were from the academic track. Student cohort of college-bound high school students is drawn from the High School and Beyond Survey of 1980 Sophomores.

SOURCE: Valerie E. Lee, OTA contractor report, 1987.

Overall, fewer women than men are interested in science and engineering majors.

To examine further the underlying interest of Blacks and women in science and engineering, OTA analyzed their patterns of academic preparation (including course-taking) and socioeconomic status.[12] **When course-taking, achievement test scores, and socioeconomic status are statistically held constant, Blacks are actually more likely than whites to be interested in majoring in science and engineering, and females are less likely than males to be interested.** High school students of lower socioeconomic status are much less likely to plan science and engineering majors than are those of high socioeconomic status. Students of low socioeconomic status are less likely to be enrolled in the academic curriculum track. The effect of that track placement is to reduce the likelihood that they will take advanced mathematics and science courses and maintain their interest in science and engineering careers.

Female participation in science and engineering may also be limited by an important "gateway" to college entrance: the mathematics portions of the Scholastic Aptitude Test (SAT) and of the Advanced College Testing (ACT) program. Several studies have shown that, even after controlling statistically for prior achievement test scores, course-taking patterns, and high school grades—women tend to get higher grades than men—women receive lower scores on these tests than men. Several observers argue that this discrepancy is due to bias in the tests' design and administration. Those responsible for the SAT and ACT argue, however, that the tests are not biased, and that differences in scores are due to differences in student preparation and family background.[13] To the extent that bias may exist and that colleges and universities make no allowances for this deficiency of the SAT and ACT, women may be deterred from science and engineering careers (see box 2-B).

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[12] See, for example, Gail E. Thomas, Center for Social Organization of Schools, Johns Hopkins University, "Determinants and Motivations Underlying the College Major Choice of Race and Sex Groups," March 1983; K.R. White, "The Relationship Between Socio-economic Status and Academic Achievement," *Psychological Bulletin*, vol. 91, 1982, pp. 461-481.

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[13] In the absence of a national high school curriculum, standardized test scores have historically been a key measure that assists college admissions offices in their decisionmaking. How college admissions officers weigh (or do not use at all) these scores relative to other factors is the overriding issue in the standardized testing controversy. A.M. Pallas and K.A. Alexander, "Sex Differences in Quantitative SAT Performance: New Evidence on the Differential Coursework Hypothesis," *American Educational Research Journal*, vol. 20, No. 2, 1983, pp. 165-182; Thomas F. Donlon (ed.), *The College Board Technical Handbook for the Scholastic Aptitude Test and Achievement Tests* (New York: College Entrance Examination Board, 1984), chs. 7 and 8; and Phyllis Rosser, "Girls, Boys, and the SAT: Can We Even the Score?" *NEA Today*, Special Edition, January 1988, pp. 48-53.

Box 2-B.—The Scholastic Aptitude Test and the American College Testing Program

Most college applicants take either one or both of these tests in their senior or junior year of high school in order to satisfy the admissions procedures of most selective colleges.[1] In 1987, just over one million students took the Scholastic Aptitude Test (SAT) and three-quarters of a million the American College Testing Program (ACT), respectively about 40 and 30 percent of the high school graduating class.[2] The ACT is traditionally taken in the Western, Midwestern, and Southern States, whereas the SAT is traditionally taken in the Eastern States and on the west coast.[3]

The Scholastic Aptitude Test.—The SAT is administered by the College Board, a nonprofit membership organization funded by more than 2,500 colleges, schools, school systems, and education associations. The test itself is developed, conducted, and scored by the Educational Testing Service, Inc., of Princeton, New Jersey, which is an independent, nonprofit organization dedicated to testing.

The SAT is designed to predict how well students will do academically during their college freshman year by measuring those developed verbal and mathematical reasoning abilities that the College Board believes are most closely related to successful college performance. The College Board does recommend, however, that other information, such as students' course transcripts, interests, and extracurricular activities should also be taken into account.[4] Nevertheless, the material that the SAT covers will not necessarily have been taught in all schools, and some of it relates to those reasoning, deductive, logical, and verbal abilities that students only acquire indirectly.

The results of the SAT are two scores: one for verbal reasoning ability and the other for mathematical reasoning ability. Performance on both parts of the test together is reported on a standardized scale from 200 to 800 points, and the College Board says that the error of measurement in any student's score is approximately 30 to 40 points.

The most controversial aspect of the SAT is the extent to which it appears to discriminate against females and minorities. In successive years of testing, both males and females score about equally on the verbal portion of the test, but on the mathematics portion males score 50 points higher than females. Blacks, on average, score 50 to 80 points lower than the entire population on each half of the test. Hispanics, on average, also score poorly, but higher than Blacks. Black and Hispanic scores have increased considerably during the last decade, by about 20 and 10 points, respectively, whereas the average score earned by the entire test-taking population each year has increased by only about 3 points. The 1987 scores, by race/ethnic group, are shown below.

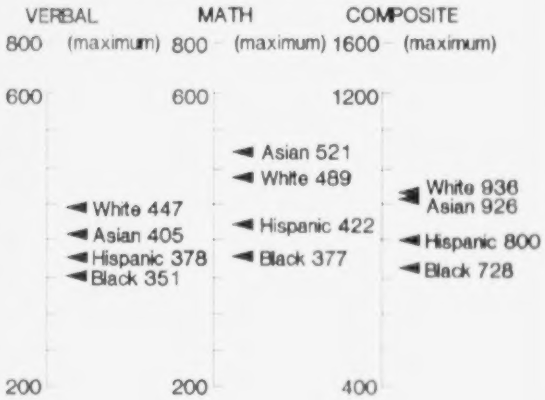
Changes in SAT test scores have sometimes been quoted as indicators of the health and productivity of the American education system. They have only limited usefulness for this purpose, however, because the tests are designed only to predict students' first-year performance in college, and because the characteristics of the students who take the test differ from year to year and State to State.

The American College Testing Program.—The American College Testing Program is an independent, nonprofit organization that administers the ACT Assessment Program, a comprehensive service designed to aid both college applicants and admissions offices. The American College Testing Program is governed by the ACT Corp., composed of elected representatives from the States that make the most use of the test and from the ACT Board of Trustees.

The heart of the ACT Assessment Program is a series of tests: English usage, mathematics usage, social studies reading, and natural sciences reading. The tests are designed to predict college performance. The results of the program are considerably more complicated than those of the SAT. They include the student's scores on these tests, comparisons of these scores with those received by previous freshmen at each institution that the student applies to, comparisons with the scores received by freshmen at comparable institutions nationally, predictions of future performance, records of the student's high school courses and grades, indications of career interests, and indications of special remedial work that the student might benefit from. Scores on the 4 tests are normalized to a common scale ranging from 1 to 36 points, with a standard error of measurement of 1 to 2 points and a mean for all college-bound students of 18 points.

Females score lower on the ACT Assessment than do males. Overall, their scores are about 1.5 points lower, and, in the case of the mathematics test, females score about 2.5 points lower. Nevertheless, the mean high school grades of female ACT Assessment takers is greater than that of males.

SAT Scores By Race/Ethnicity, 1987



SOURCE: The College Board, *1987 Profile of SAT and Achievement Test Takers*, 1987, p. v; data from Educational Testing Service

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[1] A small, but increasing, number of colleges do not require such test scores for admission. See National Center for Fair and Open Testing, *Beyond Standardized Tests: Admissions Alternatives That Work* (Cambridge, MA: FairTest, 1987).

[2] U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987* (Washington, DC: May 1987), table 71. Data for the number of high school graduates are for 1984-85.

[3] *The Chronicle of Higher Education*, Sept. 30, 1987, p. 34. For example, in 1982, 66 percent of all high school graduates in Massachusetts took the SAT, whereas only 3 percent of those in Iowa, Mississippi, North Dakota, and South Dakota did.

[4] College Entrance Examination Board, *College Bound Seniors: 1987 Profile of SAT and Achievement Test Takers* (New York, NY: College Entrance Examination Board, 1987). Thomas F. Donlon (ed.), *The College Board Technical Handbook for the Scholastic Aptitude Test and Achievement Tests* (New York, NY: College Entrance Examination Board, 1984), chs. 7 and 8.

INFORMAL EDUCATION AND INTERVENTION PROGRAMS

Although impossible to quantify, influences of families, friends, the media, and other aspects of the society on students are probably as great as those of the schools. The out-of-school environment offers opportunities to enhance students' appreciation of science and mathematics or to give them "second chances" in these areas, regardless of test-determined abilities. Programs outside of school can be both alternatives and complements to school activities. In some cases, successful informal education and intervention programs can impel communities to call for changes in curricula, course offerings, or the use of technology in the schools.

Some students are intimidated by science. Nonschool and community-based programs, including science centers and museums, can awaken interest for these students, without raising the spectre of failure.[14] (As Frank Oppenheimer, founder of San Francisco's famed Exploratorium, noted, "Nobody flunks a museum.") The number of science centers and museums is steadily increasing. A recent survey identified 150 in the United States, with 45 million visitors in 1986, up from 33 million in 1979. Half of these visitors were under 18 years of age. Science centers are also active in mathematics and science teacher training. In 1986, more than 65,000 teachers participated in such programs.[15]

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[14] Association of Science-Technology Centers, *Natural Partners: How Science Centers and Community Groups Can Team up to Increase Science Literacy* (Washington, DC: July 1987); George W. Tressel, "The Role of Museums in Science Education," *Science Education*, vol. 64, No. 2, 1980, pp. 257-260.

[15] These estimates are from the Association of Science-Technology Centers, Basic Science Center Data Survey 1988, unpublished data, February 1988. It is important to note that the majority of funding for science centers comes from local sources and admissions charges.

Photo credit: Nancy Rodger, Exploratorium, San Francisco

Science centers can provide an informal, welcoming environment for families, children, adults, and teachers to learn about science in a way different from that in the classroom. The Exploratorium has more than 400 exhibits that people of all ages can see, touch, hear, and manipulate directly. Many exhibits are attended by "Explainers," local junior high and high school students trained to answer questions and provoke curiosity about the scientific principles illustrated by the exhibit.

Science centers and other nonschool programs can open new avenues of career opportunity; for others, they enrich interests already formed. The Children's Television Workshop's *3-2-1 Contact* series is designed to interest students from 8 to 12 years old in science. Broadcast on many public television stations, it is generally regarded favorably, although data on its effects are sparse. The series is watched at least occasionally by about one-quarter of all households with children under 11 years old.[36]

A particular niche for informal science education programs is in promoting the science and mathematics interests of female and minority children. These "intervention programs" began in the 1960s and became popular in the 1970s when they attracted Federal funds. Such programs vary widely in longevity, sources of support, goals, and quality. They are often based in universities, museums, and research centers, as well as churches, community organizations, and businesses. Today, most are local initiatives funded by foundations, industry, and States. Many achieve a good deal of success from limited resources (see box 2-C).

A study by the American Association for the Advancement of Science notes that early, sustained applications of excellent instruction can bring minority achievement to the same level as that of white males.[37] Indeed, some suggest that the techniques applied by intervention programs, such as hands-on experiments and other activities conducted in

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Excluding three centers operated directly by the Federal Government, an average of 2 percent of science center funding comes from Federal sources.

[36] Research Communications, Ltd., "An Exploratory Study of 3-2-1 Contact Viewership," National Science Foundation contractor report, June 1987.

[37] Shirley M. Malcom et al., *Equity and Excellence: Compatible Goals*, Publication 84-14 (Washington, DC: American Association for the Advancement of Science, December 1984).

Box 2-C.—Characteristics of Intervention Programs That Work

Over the past 10 to 20 years, special programs have been used to encourage children's interest and proficiency in academics and especially in science and engineering. Programs have worked in school and out of school, with students of all ages, cultures, and races; with youngsters of exceptional mathematics and academic achievement and with high school dropouts; in fields from agriculture to engineering. Some programs use professional experts and the latest in testing and computer technologies; others work on shoestring budgets with egg cartons and volunteers. From these experiences, both successes and failures, have emerged lessons about what makes an intervention program work. The characteristics of successful intervention programs are listed below:

- clearly defined educational goals,
- high expectations among teachers and leaders,
- committed leadership,
- role models to motivate students,
- peer support with critical mass of students,
- student commitment and investment (increased study time),
- hands-on laboratory experience,
- assessment and feedback to students,
- specific goals for minorities or women,
- recruitment,
- financial aid (fellowships and traineeships augmented by research assistantships),
- multi-year involvement with students, and
- program evaluation based on student achievement.

SOURCES: Office of Technology Assessment, 1988; Government-University-Industry Research Roundtable, *Nurturing Science and Engineering Talent* (Washington, DC: National Academy of Sciences, July 1987), pp. 36-38.

small groups (see box 2-D), could usefully be disseminated to the entire school-age population.

Most programs also require extraordinary staff commitment and support, which are not easy to replicate from location to location. However, the Mathematics, Engineering, and Science Achievement (MESA) program, founded in the San Francisco Bay area in 1970, expanded throughout California and has been successfully transferred to other States (see box 2-E). Today MESA offers a model adaptable to students in junior high school through college.

Intervention programs do, however, pose a dilemma to schools and school districts. Ideally, schooling would adapt to and cultivate each student's unique aptitudes and interests, and be equally excellent nationwide. That long-term goal will not soon be reached. In the meantime, some commentators suggest that intervention programs outside schools are vital because the schools themselves are so impervious to reforms designed to improve the progress of students disaffected from science. Others feel that intervention programs can work well in schools. Some school districts, therefore, have welcomed intervention programs, while others have regarded them with some suspicion.

It is not clear why females and members of some racial and ethnic minority groups, on average, begin to fall behind in mathematics and science preparation as early as elementary school, and are less likely than white males to persist in science and engineering. But intervention programs can help reduce these differences by instilling confidence and increasing motivation—attitudes not easily measured. **Intervention programs effectively encourage women**

THE
MATH
BOOK

Photo credit: William Mills, Montgomery County Public Schools

Parents can help their children to prepare for school work in mathematics and science from an early age. But many parents lack the confidence in these subjects to encourage their children. Programs such as "Family Math," devised at the Lawrence Hall of Science, California, are designed for both parents and children to use together. The program has expanded to many cities around the Nation.

Box 2-D.—Center for the Advancement of Academically Talented Youth, The Johns Hopkins University

The Center for the Advancement of Academically Talented Youth (CTY) has gained an international reputation for identifying and furthering the education of mathematically and verbally talented students at the junior and senior high school levels. Dr. Julian Stanley founded the Study of Mathematically Precocious Youth in 1971 to identify mathematically talented adolescents. CTY's Regional, National, and International Talent Searches have identified more than 70,000 highly able students since its inception in 1979. Most of the CTY programs, which are designed for 12- to 16-year-olds, are held during the summer months, although Expository Writing and Science/Mathematics Tutorials-By-Mail are available to participants during the academic year.

CTY relies on standardized tests, particularly the Scholastic Aptitude Test, to identify youngsters for its programs. For many high-talent students, CTY claims, the program is the first opportunity to match their learning with their ability. While participation in CTY programs can result in early college admission for some, the principal aim is to enrich the preparation of students. CTY classes are demanding and span the humanities, mathematics, computer science, and the natural sciences. To provide students with individualized instruction that caters to their differing ability levels, the program matches participants with instructors in one-to-one exchanges at various points during the course. CTY also helps students negotiate with their home schools for appropriate course placement and credit for CTY work. Letter grades courses are not given unless specifically requested by the student's school. Nevertheless, upon completion of the program, CTY does provide each student with a detailed description of his or her performance, and all students take the College Board Achievement Test in the appropriate subject area. In addition, CTY does offer some college scholarships for outstanding students.

CTY conducts extensive followups on its participants. In 1986, three groups of former participants were asked to describe their current educational and career development. More than 90 percent were then attending college. Many responded in essay form about their CTY experience; one student wrote in her evaluation of classes: "There is a feeling that I can't find anywhere else in the world . . . . I will miss CTY. It is here that I am most alive." Students feel comfortable and exercise their full potential in an informal environment which, given the ages of students, can be as important to their development as is academic preparation. The same student noted, "At CTY, I belonged. I felt better about myself than I had since I entered junior high school."

Box 2-E.—The Mathematics, Engineering, Science Achievement Program

The Mathematics, Engineering, Science Achievement (MESA) Program, begun in 1970 and based at the Lawrence Hall of Science in Berkeley, California, aims to increase the number of Black, Hispanic, and Native American students in California that complete 4-year university degrees in mathematics, science, or engineering. The program operates under the auspices of the University of California at Berkeley.

Working with junior high and high school students as well as undergraduates, the MESA Program has proven effective at recruiting and retaining minority students in these fields. MESA is widely acclaimed, and has been replicated in other States, including Colorado, New Mexico, Washington, Oregon, Kansas, and Utah. Activities offered by the program include internships, field trips, incentive awards, counseling, college freshman orientation and guidance, financial aid and scholarships, and the formation of student study groups to foster cooperative learning. The program reached 7,800 students in 1985-86, and operated in one-quarter of all California high schools with a predominantly minority enrollment. Most of the high school graduates who have participated in MESA programs have gone on to mathematics-based majors.

The MESA Program offers a Minority Engineering Program (MEP) and a Pre-College Program. The former operates through about 15 centers, most on campuses of the California State University and the University of California, and in 1985-86,[1] served about 2,500 students. The latter operates in 17 centers, also mainly on college campuses, and served over 5,000 students drawn from 60 school districts. A particular emphasis of the Pre-College Program is encouraging students to take the optional preparatory series of classes in mathematics and science in junior high and high schools, which are very difficult to make up once a student has missed them.

Most of the MESA Program's funds ($2.34 million) have come from the State of California, and other sources have been over 40 corporations and foundations, including a $610,000 3-year grant from the Carnegie Corp. MESA also operates programs for junior high and high school teachers (more than 200 attended workshops on hands-on teaching methods in mathematics and science in 1985-86), and has close links with other intervention programs, such as the University of California at Berkeley's Professional Development Program, EQUALS, and the South East Consortium for Minorities in Engineering.

The effectiveness of MESA's MEP is indicated by the retention rates of its participants. For example, 60 percent of MEP freshmen, after 3 years, remain in college, compared with 47 percent of all students. In engineering, Black and Hispanic MEP students have retention rates of 64 percent and 57 percent, respectively, after 2 years (compared with 13 percent and 21 percent for Black and Hispanic nonparticipants).[2]

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[1] All data reported below are for 1985-86.

[2] These data are for University of California students only, though statistics from the California State University system are similar. "Retention rate" is percent enrolled at the university after 2 or 3 years of study. California Postsecondary Education Commission, *Retention of Students in Engineering*, A Report to the Legislature in Response to Senate Concurrent Resolution 16, 1985 (Sacramento, CA: December 1986).

and minorities to consider science and engineering careers. The techniques used by these programs would also be effective with the general population of students. Institutionalizing intervention techniques in the schools, without robbing them of their appeal, would seem promising. Such institutionalization would depend on training teachers to use intervention techniques in classrooms.

In the decentralized American education system, even the most successful programs are extremely difficult to replicate. The inherent conservatism of local school authorities is one impediment. Another is the difficulty of generating the community and family support necessary to recruit students and maintain programs' momentum. The fundamental problem is that special intervention programs should not be necessary. That they are, some argue, is an indictment of America's education system, which has fallen short of fulfilling the democratic ideals of equal opportunity and of schools as centers of learning.

OPPORTUNITIES FOR FEDERAL INFLUENCE ON THE TALENT POOL

The Federal Government has only a modest influence on elementary and secondary mathematics and science education. If public education is the collective responsibility of the States and the school districts (which together bear most of its cost), then school districts and States must both examine what they can do to improve science and mathematics experiences for all of their students and address the specific problems that inhibit the development of scientific and engineering talent.

The Federal Government in the past has made attempts, with some success, to improve mathematics and science education in the schools. The lead agency for Federal intervention in school mathematics and science education has been the National Science Foundation. Although NSF has been interested principally in students who are most likely to become scientists and engineers, there are now renewed calls for NSF to take a more comprehensive approach and "broaden the base" of students learning science.[38] In fiscal year 1988, NSF's total precollege effort is funded at about $90 million, all of it through the Science and Engineering Education Directorate.

Following the so-called Sputnik Crisis, Congress passed the National Defense Education Act of 1958, which provided extensive funding to school districts for science equipment, supplies, and teacher training. In the early 1960s, Congress also increased funding of NSF's science education activities until, at its peak, about half of NSF's budget went to education and the bulk of that to its popular program of teacher training institutes. Data suggest that, in those years, about half of all high school mathematics and science teachers attended at least one such institute. A small program of similar activities is still funded by NSF.[39]

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[38] Michael S. Knapp et al., *Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation* (Menlo Park, CA: SRI International, June 1987). Congress ordered the National Science Foundation to commission this study of the areas in which the National Science Foundation, given its strengths and weaknesses, could best intervene in school mathematics and science education.

NSF's teacher institutes were designed to bring teachers up-to-date with advances in science and were very popular. Many teachers, supervisors, and leaders of the science education community fondly remember these programs as bringing an espirit de corps to the teaching profession, and updating teachers' scientific knowledge, particularly in experimental work. However, since attendance at the institutes was voluntary, many teachers (often the least interested and least well qualified) shunned them. The effectiveness of the institutes has been debated, both because of the difficulty of defining and researching the effectiveness of any teacher improvement program and because the institutes were not systematically evaluated at the time.[40] Any future replication of the institutes program would be costly, and it might require $500 million to $1 billion, spread over several years, to put all existing secondary mathematics and science teachers through at least one institute program. But a second generation of institutes would likely remedy past mistakes and benefit from successful teacher improvement activities that have been funded by school districts and foundations (for example, see box 2-F).[41]

Renewed concern about the state of mathematics and science education in the schools led Congress to pass the Education for Economic Security Act of 1984, which has provided $40 million to $140 million annually, mainly for teacher training and educational activities.[42] The Federal Government, via

Box 2-F.—Urban Mathematics Collaboratives

This innovative program is designed to support and reinvigorate mathematics teachers in 11 inner-city centers. Each mathematics collaborative brings together a community-wide advisory board of teachers and business, civic, and university leaders, with a part-time administrative staff. Collaboratives currently exist in Cleveland, Los Angeles, Minneapolis/St. Paul, Philadelphia, San Francisco, Durham, Memphis, New Orleans, Pittsburgh, San Diego, and St. Louis. The program was started with a Ford Foundation grant in 1984. To date, the foundation has committed over $2 million. Each collaborative receives Ford Foundation support for 3 to 5 years in the expectation that each will become a self-sustaining program funded by community businesses, industries, colleges, universities, and other civic and cultural organizations.

Specific collaborative activities for mathematics teachers include industrial internships, exchange programs with colleges and industries, evening symposia, newsletters, and summer workshops. By fostering collegiality among mathematics teachers and increasing the human and financial resources available to teachers, the projects seek to reduce teachers' isolation and to boost their professional enthusiasm. To further the professional goals of the collaboratives, the Foundation has established a Technical Assistance Project that serves as an information clearinghouse on mathematics education and facilitates network communication. The Foundation also funds evaluation of the project through the Wisconsin Center for Educational Research.

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[39] The National Science Foundation remains cautious and makes no claims either for the institutes' effectiveness or ineffectiveness. But many science educators think that the institutes were remarkably successful. A study by the Congressional Research Service in 1975 found that the institutes were of great value. U.S. Congress, Congressional Research Service, *The National Science Foundation and Pre-College Science Education: 1950-1975* (Washington, DC: U.S. House of Representatives, Committee on Science and Technology, Subcommittee on Science, Research, and Technology, January 1976), Committee print. Hillier Krieghbaum and Hugh Rawsom, *An Investment in Knowledge* (New York, NY: New York University Press, 1969) suggest that the institutes were effective. Victor L. Willson and Antoine M. Garibaldi, "The Association Between Teacher Participation in NSF Institutes and Student Achievement," *Journal of Research in Science Teaching*, vol. 13, No. 5, 1976, pp. 431-439, found some modest positive effects. Also see Knapp et al., op. cit., footnote 38, vol. 1, p. 130.

[40] The General Accounting Office reviewed research on the National Science Foundation-funded institutes and found little or no evidence that such institutes had improved student achievement scores. U.S. General Accounting Office, *New Directions for Federal Programs To Aid Mathematics and Science Teaching*, GAO/PEMD-84-5 (Washington, DC: Mar. 6, 1984).

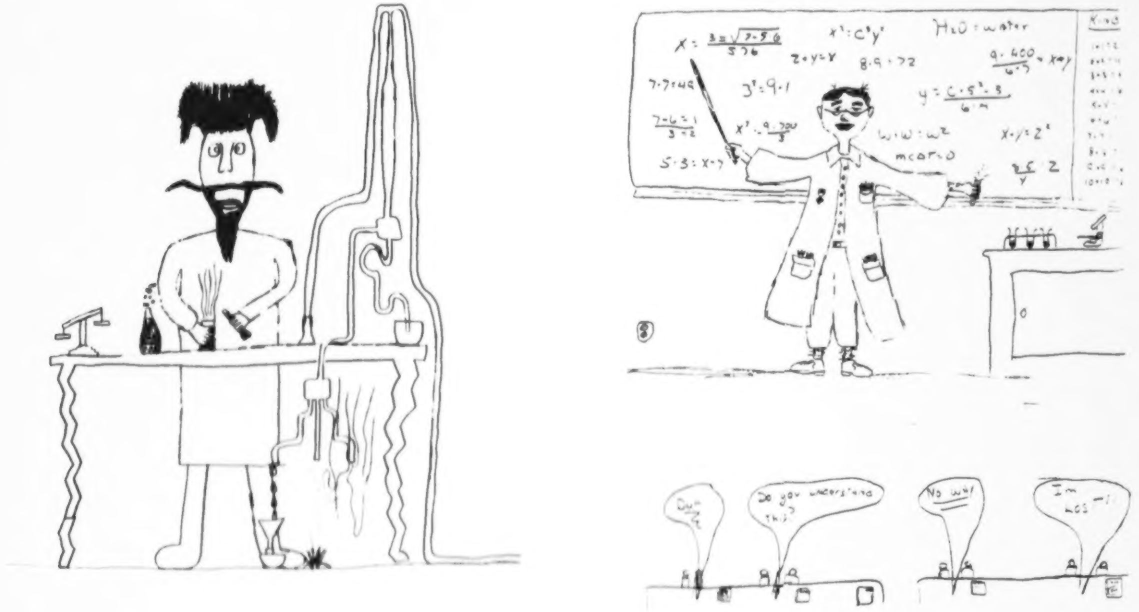
[41] The National Science Foundation has also funded curriculum development efforts and informal education activities, such as educational television and science centers, with some success.

[42] Marks, op. cit., footnote 18.

both NSF and the Department of Education, has also funded research on mathematics and science education, as well as data collection. These activities have been very valuable in giving the Nation a picture of what is happening today and how things might be improved.

Future Federal efforts to support science and engineering education can leverage Federal funds if they stress partnerships with programs funded by States, school districts, private industry, and business. An advantage of this approach, other than reducing Federal outlays, is that the burden of evaluating program outcomes is shared by all participants. When this cannot be worked out, however, Federal funds may be the only mechanism for improving the quality of mathematics and science education.

In summary, ways to ensure adequate production of scientists and engineers fall into two distinct groups. One is to enlarge the talent pool, the other is to retain those already in it. Both cast schools as the agent for recognizing and nurturing talent. To assist in these tasks, the system of schooling must become more sensitive to learning styles and varying rates and patterns of children's intellectual development,[41] and more open to community-based programs and institutions. As a Nation, we can explore ways by which science and engineering could more freely welcome those who come to the professions by nontraditional paths.


H₂O = water
Duh ?
Do you understand this?
No way
I'm Lost!

Drawings by elementary school children in response to the question "What does a scientist look like?" (1988).

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[41] There is pressure for redirecting American education to focus more clearly on developing "higher order thinking skills." See Lauren B. Resnick, *Education and Learning to Think* (Washington, DC: National Academy Press, 1987). In science, the focus is on investigative and interpretive skills as well as on factual recall. See Robert E. Yager, "Assess All Five Domains of Science," *The Science Teacher*, vol. 54, No. 7, October 1987, pp. 33-37. There are also suggestions that teaching should be better tailored to suit the way women and minorities learn. Christine I. Bennett, *Comprehensive Multicultural Education: Theory and Practice* (Boston, MA: Allyn & Bacon, 1986), ch. 4 and 5; Mark A. Uhlig, "Learning Styles of Minorities to Be Studied," *New York Times*, Nov. 21, 1987, p. A29; Eleanor Wilson Orr, *Twice As Less: Black English and the Performance of Black Students in Mathematics and Science* (New York, NY: W.W. Norton & Co., 1987).

Chapter 3

Higher Education for Science and Engineering

Photo credit: Auburn University and The Chronicle of Higher Education

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Chapter 3

Higher Education for Science and Engineering

DIVERSITY OF INSTITUTIONS, STUDENTS, AND DEGREES

The 3,300 universities, colleges, and engineering institutes in the United States enroll a larger proportion of young adults than in any other nation. About 12 million students are enrolled in institutions of higher education; over 2 million of these are first-time freshmen.[1] Half of these students will eventually receive bachelor's degrees. For the last three decades, 30 percent of bachelor's degree recipients (that is, about 9 percent of each high school graduating class) received their degrees in science or engineering, including social sciences. In recent years, about one-tenth of these bachelor's-level scientists and engineers have gone on to earn science or engineering doctorates.[2]

These broad patterns disguise a great deal of variation. Large research universities, small liberal arts colleges, historically Black institutions, 2-year institutions, technical institutes, and other public and private institutions of all kinds make American higher education extraordinarily diverse in size, purpose, and structure. Each type of institution provides a unique environment for developing talent and encouraging persistence in pursuit of a degree. While this chapter concerns characteristics of educational environments and their students, its emphasis is on institutions as producers of scientists and engineers at all degree levels. Of course, institutions of higher education have many other functions besides producing scientists and engineers, from vocational training to the cultivation of western civilization's artistic and cultural traditions.

Although 30 percent of baccalaureates are awarded in science and engineering, the relative popularity of different fields has shifted substantially with events in the job market of the last three decades. Increasing college enrollments, which was the trend until 1982, meant more science and engineering baccalaureate recipients; in contrast, the proportion continuing on to Ph.D. study reflects market demand, the availability of Federal research and development (R&D) funds, and direct student support (see figure 3-1).[3] There is also substantial variation in science and engineering by sex, race, and ethnicity of degree recipients. White males are far more likely to earn degrees in science and engineering than women, Blacks, or Hispanics (see figure 3-2). These differences—which vary from field to field—have narrowed in the past 15 years, but are still generally large.

Most fields of graduate study in the sciences, as distinguished from engineering, are oriented toward the academic as well as the industrial job market; somewhat less than half of Ph.D. scientists work in academic institutions. The Ph.D. is the basic professional degree in most fields of science, and most science students seek research or teaching positions. Despite growing undergraduate enrollments from the late 1960s to the early 1980s, a stagnant academic job market and slower growth in Federal research funds have left many young Ph.D.s "underutilized."[4] Many institutions, beset by a faculty

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[1] Other notable statistics on the total enrolled population are that 60 percent are full-time students and two-thirds attend universities and 4-year institutions. Among first-time freshmen (who represent roughly 80 percent of high school graduates), the ratio of full- to part-time students is two to one, but equal numbers are enrolled in 2- and 4-year institutions. See U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987* (Washington, DC: May 1987), tables 104-110, 154. The focus of this chapter is on full-time students enrolled in America's 1,500 4-year colleges and universities.

[2] Natural sciences and engineering bachelor's degrees account for an average of 20 percent of the baccalaureates awarded during this period. National Science Foundation, *Science and Engineering Degrees, 1950-80: A Source Book*, NSF 82-307 (Washington, DC: 1982).

[3] Betty Vetter and Henry Hertzfeld, "Federal Support for Science and Engineering Education: Effect on Output of Scientists and Engineers 1945-1985," OTA contractor report, 1987. These relationships are elaborated below.

[4] The National Science Foundation adds the rates of unemployed and "underemployed"—those who are involuntarily in nonscience or engineering jobs or working part-time but seeking full-time employment—to define an "underutilized" segment of the science and engineering work force. In 1986, 6.5 percent of scientists and 2.3 percent of engineers, at all degree levels, were underutilized. National

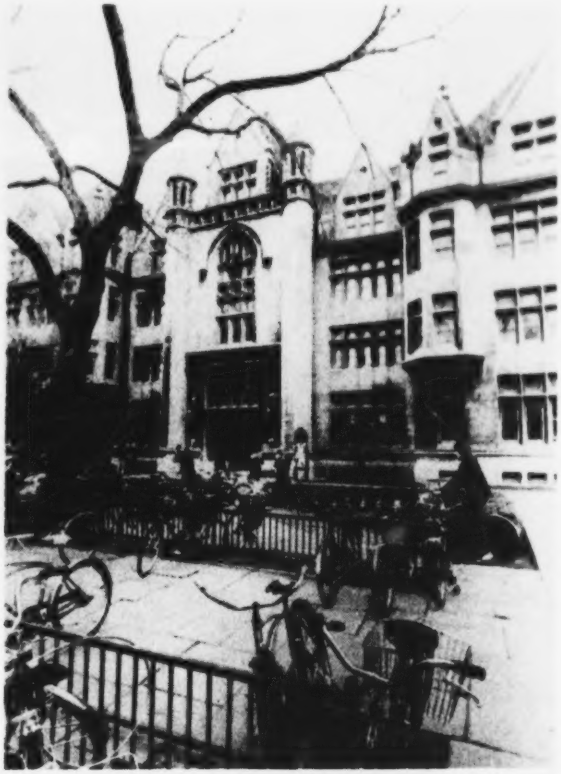
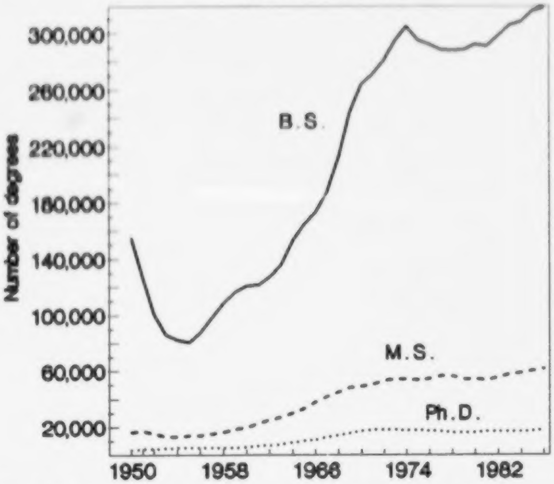


Photo credit: University of Chicago and The Chronicle of Higher Education

Photo credit: University of Massachusetts, Boston, and The Chronicle of Higher Education

American higher education institutions are extremely varied, ranging from internationally renowned research universities to small liberal arts colleges emphasizing undergraduate teaching. Some smaller institutions focus on local students, certain types of students (e.g., minority institutions), course offerings (e.g., engineering schools), or course structure; while others emphasize a diverse student body and comprehensive curriculum. This diversity has been a strength of American education and research training.

Figure 3-1.—Science/Engineering Degrees, by Level, 1950-86



SOURCE: U.S. Department of Education, Center for Education Statistics (B.S. and M.S.); National Research Council, *Survey of Doctorate Recipients* (Ph.D.).

tenured largely during 1960s-era expansion, curtailed their hiring in the 1970s. Full-time graduate enrollments in science and engineering have grown since the early 1970s. If not for the influx of foreign graduate students, however, these enrollment increases would have been less. Retirements and turnover of faculty in the mid-1990s, combined with a resurgence in undergraduate enrollments later in the decade, may eventually relieve these pressures.[5] Until then, the attractiveness of an academic career will pale for many students.

In engineering and some fields of science (notably earth sciences and computer science), the bachelor's or, increasingly, the master's degree is the most important professional degree. The employment markets for these fields are dominated by industry; for example, 80 percent of engineers work for private companies.[6] Unlike the Ph.D.-oriented fields, these fields respond to industrial, rather than academic,

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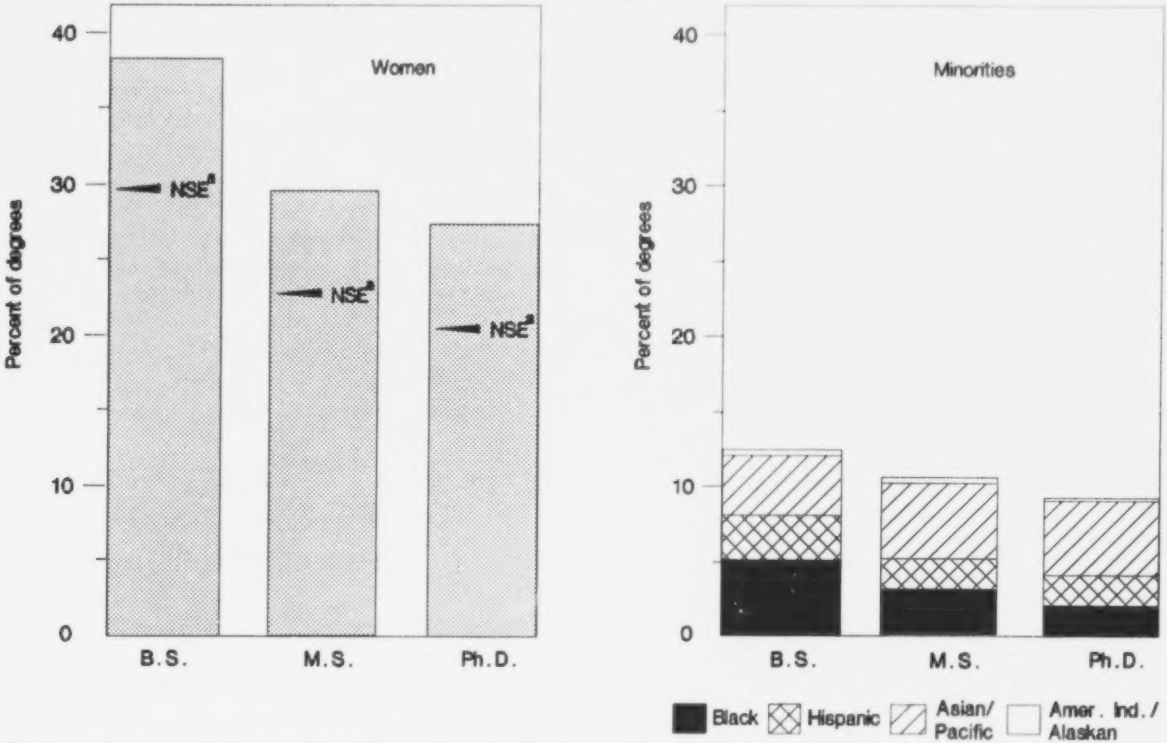
(continued from previous page)
Science Board, *Science Indicators: The 1985 Report*, NSB 85-1 (Washington, DC: 1986), pp. 67-68.

[5] Institutions in the higher education system will absorb these trends in different ways. The research universities will have the most financial latitude to accommodate flux in faculty and research positions as well as student enrollments. See, for example, Harvey Brooks, "The Research University: Doing Good, and Doing It Better," *Issues in Science and Technology*, vol. 4, No. 2, winter 1988, pp. 49-55.

[6] U.S. Congress, Office of Technology Assessment, "Preparing for Science and Engineering Careers: Field-Level Profiles," staff paper, Jan. 21, 1987.

Figure 3-2.—Science/Engineering Degrees, by Level, Sex, and Race/Ethnicity, 1986



[a] NSE is natural science/engineering, which does not include the social sciences.

SOURCE: U.S. Department of Education, Center for Education Statistics (B.S. and M.S.); National Research Council, *Survey of Doctorate Recipients* (Ph.D.).

needs. Because their periods of training are shorter, enrolled students can react more quickly to employment opportunities. These fields, not coincidentally, have been the ones that experience enrollment and employment booms, and subsequent busts. When fields boom (the most recent examples are engineering and computer science), faculty shortages develop. Foreign faculty have proven vital to maintaining teaching capacity in these fields. U.S. citizens have generally sought high-paying baccalaureate-level industrial employment rather than graduate study in pursuit of faculty positions.

Federal influence over higher education is especially forceful at the graduate level. Federal fellowships and other forms of assistance are awarded to support specific graduate students in specific fields of study. Federal R&D programs can also be highly influential, since they provide employment opportunities for researchers in universities, industry, and government, and assistantships for students. Before they aspire to research apprenticeships and careers in science and engineering, however, students must acquire undergraduate educations that prepare them for graduate study or, alternatively, convince them that research is not their destiny. The character of the undergraduate experience is usually decisive for imparting the skills and expectations needed for participation in science or engineering.

UNDERGRADUATE EDUCATION

Key Questions

- How well does undergraduate education nurture talent?
- What leverage or influence does the Federal Government have on undergraduate education?
- Are there particular undergraduate environments in science that encourage students to pursue a Ph.D.? Are certain environments particularly successful with specific groups?

Key Findings

- Interest by freshmen in science and engineering is declining slightly, while majors such as business are increasingly popular. Science and engineering students continue to have higher high school grade point averages and Scholastic Aptitude Test (SAT) scores than those entering other majors.
- Any action that increases the size or changes the composition of the entire undergraduate population, such as the G.I. bill and Title IX (which outlawed sexual discrimination), is likely to be reflected in the number of baccalaureate awards. Science and engineering fields share in these changes.
- Research universities, in absolute terms, produce the largest number of students that go on to Ph.D.s. in science and engineering. But small liberal arts and technical colleges with some active research produce, in relation to their size, a remarkable number of students who eventually earn Ph.D.s. in these fields.
- Science and engineering majors are similar to other students in their sources and extent of financial aid. Undergraduate loan burdens do not seem to affect decisions by the majority of students to pursue graduate degrees.

Higher education, once an optional route to occupational mobility, is now a necessity for those seeking admission to the professions. The baccalaureate is a crucial, but by no means final, credential for employment, while institutions differ markedly in the educations they provide. The process of recruiting and sorting student talent is reciprocal: institutions' reputations, fees, and locations influence the choices of students and their families, while the students' academic profiles guide (but do not alone determine) institutions' admissions decisions.[7] Institutions will have important effects on students' future careers, influencing their choices of majors, their friends, and their likelihoods of pursuing graduate study. But a student's career interest and planned major will also influence the choice of college. Data on the "intentions" of entering freshman capture the link between actual college enrollments —the net effect of mutual recruitment and sorting— and declared career plans.

Freshmen Intentions To Major in Natural Science and Engineering

The expressed intentions of entering freshmen indicate that fewer students today are interested in natural science and engineering majors than at the end of the last decade. In 1978, 27 percent, or about 286,000, of first-time, full-time freshmen entering the Nation's 4-year colleges and universities, planned to pursue majors in natural science or engineering. By 1986, 24 percent (246,000) expressed such interest.[8]

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[7] Applications for admission to higher education institutions have been rising since 1986. Perhaps this is due to effective college marketing. Students seem more willing to apply to institutions that they ordinarily would consider beyond their reach academically and financially. Because the number of students available to become freshmen has been broadcast as demographically depressed, multiple applications increase the prospect of choice. See Robert Rothman, "Surprise: Freshman Enrollment Is Surging," *Education Week*, vol. 7, No. 7, Oct. 21, 1987, pp. 1, 21. From the institution's perspective, a multivariate "predicted performance" model that accounts for differences in the high schools from which students apply, as well as standardized test scores, grades, extracurricular activities, etc., is preferred in making admissions decisions. See Hunter M. Breland, Educational Testing Service, "An Examination of State University and College Admissions Policies," research report, January 1985.

[8] Data are from the Cooperative Institutional Research Program's annual survey of freshmen in American colleges and universities. Freshmen intentions to major in fields are taken as an indicator of degree trends 4 to 5 years later. The correlation is strong and positive, but variable by field. Kenneth C. Green, "Freshman Intentions and Science/Engineering Careers," OTA contractor report, December 1987. Also note that in this section we use the more restrictive designation "natural science and engineering" (omitting social science) to estimate career interest and size of the science and engineering talent pool.

The decline has been neither steady nor consistent. Freshman interest in some majors, such as computer science and engineering, rose substantially in the early 1980s as students sought careers in high-growth fields.[9] Enrollments in both fields began to decline in 1984, however, and by 1986 their shares of freshman major intentions had slipped back to where they had been in the late 1970s. Freshmen interest in becoming research scientists also declined by more than one-quarter between 1978 and 1986. This drop in freshman interest could be interpreted as a delayed response to a market perceived as offering too few desirable positions for those graduating with degrees in science. It is a disturbing trend and an early warning signal to those concerned about replenishing the research work force.

Blacks and Hispanics represent 8 and 2 percent, respectively, of the freshmen intending majors in the natural sciences and engineering, and Asians 6 percent. Changes in the distribution of freshman preferences of Asian and Black students by broad field can be observed in table 3-1; for all broad fields of natural science and engineering, the proportion of whites declined from 1978 to 1986 while the proportions of Asians and Blacks rose. In general, Cooperative Institutional Research Program (CIRP) data indicate that science-interested freshmen are more likely than their peers in other fields to report "A" or "A-" grade point averages in high school, and to report having spent more time on high school homework. They are more confident of their abilities and have higher degree aspirations. More of these high school "high achievers," however, are choosing other majors, particularly business, than did so in the past.[10]

How well do freshmen intentions predict degree outcomes? A 1986 CIRP followup survey of the freshman cohort of 1982 shows that retention to completion of the baccalaureate varies by discipline. For example, 70 percent of freshman business majors earn the baccalaureate in business 4 years later, and over 60 percent of education and social sciences majors receive degrees in these fields. In natural science and engineering fields, the retention rates are lower, ranging from a low of 38 percent in the physical sciences to a high of 58 percent in engineering. In general, these fields lose twice as much talent to fields other than natural sciences and engineering fields than they gain. As seen in figure 3-3, the "survival rate" for the 1982 freshman cohort in four broad fields can be measured in several ways. (Attrition from a natural science or engineering major, it should be remembered, can represent a gain elsewhere.) In the biological sciences, physical sciences, and engineering, 5 to 10 percent of the bachelor's

Table 3-1.—Freshman Preferences for Various Undergraduate Majors, by Selected Racial/Ethnic Group, 1978 and 1986[a]

	Asian		Black		White[b]	
	1978	1986	1978	1986	1978	1986
Natural science and engineering						
Physical sciences	1.9	4.5	6.0	10.3	91	83
Biological sciences	0.9	6.3	5.8	6.4	91	84
Pre-medicine	2.9	7.4	7.9	9.9	87	79
Engineering	2.2	5.8	6.8	7.4	89	84
Other majors						
Social sciences	0.9	2.2	12.6	9.8	84	85
Arts & humanities	0.9	2.2	6.3	6.2	91	90
Business	0.9	2.0	9.8	11.3	88	85
Education	0.5	0.6	8.5	6.5	90	91
All other[c]	1.1	2.9	8.8	9.4	88	86

[a] Freshmen of selected racial/ethnic group as a percentage of all freshmen planning to pursue majors in selected fields.
[b] Percentages have been rounded.
[c] Includes nursing, allied health, architecture, and undecided students, among others.

SOURCE: Kenneth C. Green, "Freshman Intentions and Science/Engineering Careers," OTA contractor report, 1987.

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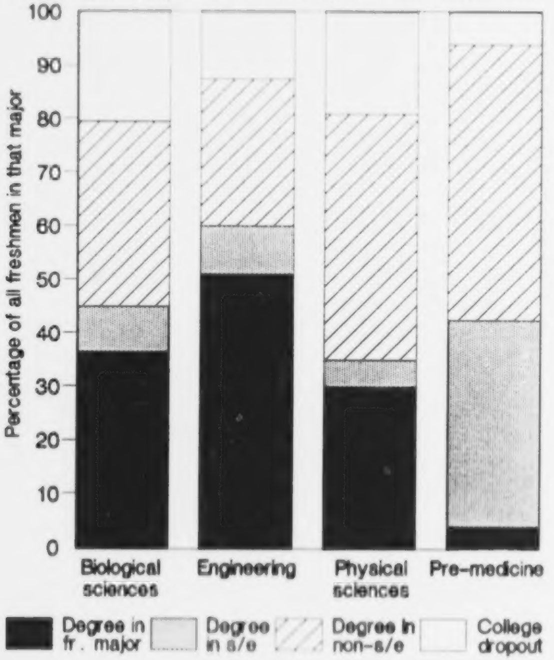
[9] Alexander W. Astin et al., *The American Freshman: Twenty Year Trends* (Los Angeles, CA: University of California at Los Angeles, Higher Education Research Institute, 1987), pp. 14-15.

[10] When interest in natural science and engineering majors is analyzed for the high achiever student population (those with "A" or "A-" high school grade point averages), the proportion of Asians increases from 6 to 8 percent, while the proportion of Blacks decreases by half to 4 percent. Eighty-five percent of the high achiever population is white.

Figure 3-3.—Natural Science/Engineering B.S. Degree Attainment, by Freshman Major, 1982 Freshmen



SOURCE: Kenneth C. Green, OTA contractor report, 1987. Based on data from the Cooperative Institutional Research Project, University of California at Los Angeles.

recipients earn a degree in a field other than the freshman major but still within the natural sciences and engineering.

Trends in Science and Engineering Baccalaureates

The number of science and engineering baccalaureates has risen slightly as a percentage of the 22-year-old population, although its share of all baccalaureate degrees awarded has been fairly constant during the past two decades. The distribution of these degrees by field has varied considerably in response to economic developments, Federal and State policies, and social attitudes (see figure 3-4). Physics degrees fell during the 1970s and are still recovering; one-third of physics graduates continue with graduate study. With earth scientists in surplus owing to the decline in the petroleum and mining industries, baccalaureates in these fields have been declining sharply since 1982. A decline in mathematics baccalaureates in the late 1970s was accompanied by a rise in computer science degrees; mathematics is now rebounding somewhat. Degrees in biology have been declining in the past 10 years. Baccalaureates in the social sciences peaked in 1974, after a period of substantial growth, and have been declining ever since.[11]

Women in Science and Engineering

Women have never been well represented[12] among recipients of science and engineering baccalaureate degree awards (see figure 3-5). Women received about 38 percent of science and engineering bachelor's degrees (heavily concentrated in the social sciences (43 percent) and life sciences (44 percent)) in 1986.[13] Although women have made gains across the board in their share of science and engineering baccalaureates, since 1984 their share has leveled off, and in computer science, engineering, biological sciences, and the physical sciences is declining slightly.[14] Yet CIRP reports that in 1986 women were twice as likely as men to be interested in medical careers (often anchored by an undergraduate major in biology) and significantly more likely to be interested in research.[15]

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[11] Betty M. Vetter and Eleanor L. Babco, *Professional Women and Minorities: A Manpower Data Resource Service*, 7th ed. (Washington, DC: Commission on Professionals in Science and Technology, December 1987), pp. 137, 151, 199.

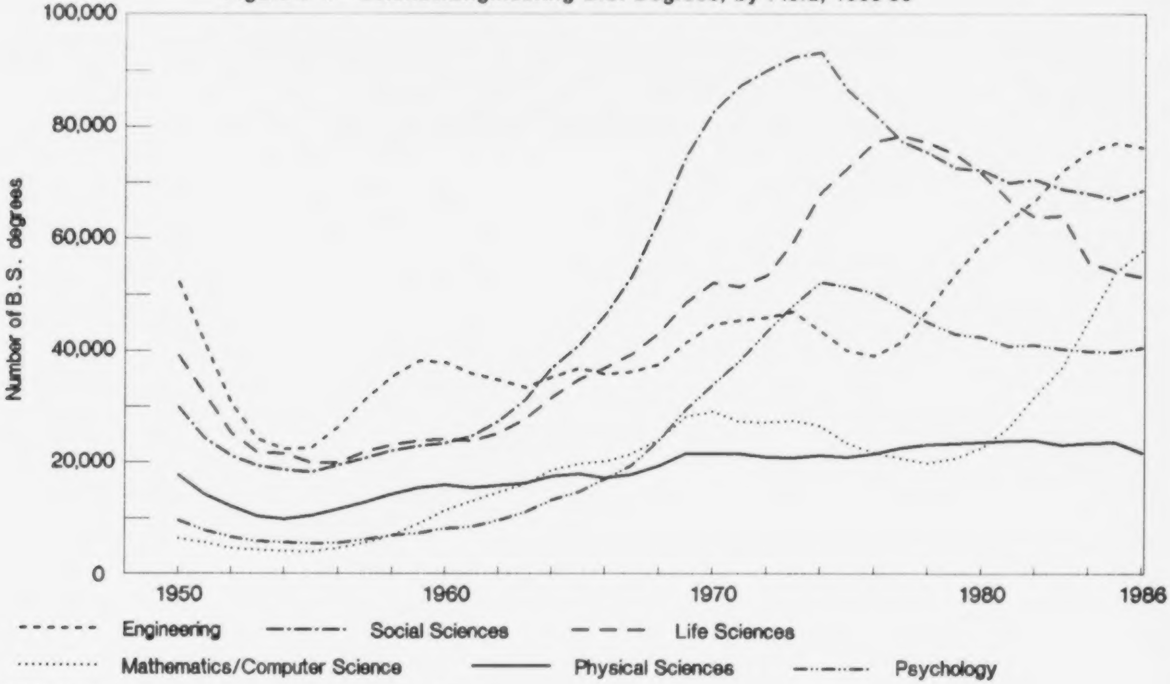
[12] The widespread use of the terms "underrepresented" and "overrepresented" is troublesome. Both terms assume some "normal" level of representation relative to a base population. That population could be the total U.S. population, the size of the college-age (18- to 24-year-olds) cohort, or the number of undergraduate students enrolled. The referent is seldom clear; the terms are not used throughout this report. For further discussion, see U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering—A Technical Memorandum*, forthcoming, summer 1988.

[13] Vetter and Babco, op. cit., footnote 11, p. 54.

[14] Betty M. Vetter, "Women's Progress," *Mosaic*, vol. 18, No. 1, spring 1987, pp. 4-5.

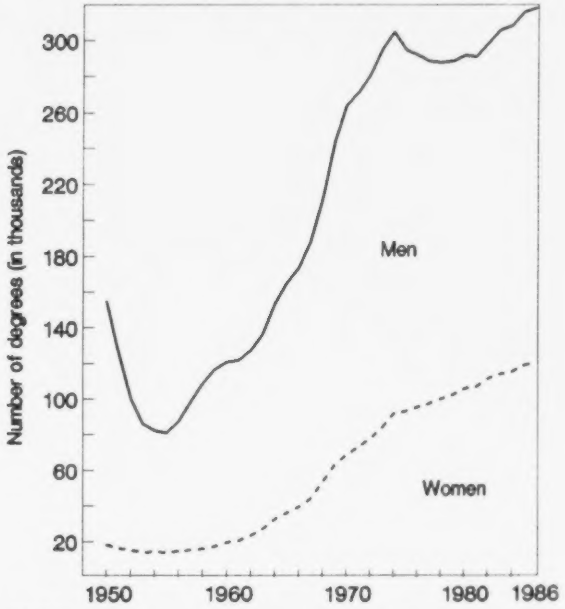
[15] Green, op. cit., footnote 8. The gap between aspirations and realization has been explained by some as a "chilly climate" for women that still prevails in many college classrooms. Roberta M. Hall and Bernice R. Sandler, *The Classroom Climate: A Chilly One for Women?* (Washington, DC: Association of American Colleges, Project on the Status and Education of Women, 1982); Roberta M. Hall and Bernice R. Sandler, *Out of the Classroom: A Chilly Campus Climate for Women?* (Washington, DC: Association of American Colleges, Project on the Status and Education of Women, October 1984). In terms of the thinning ranks of the research work force noted earlier, women's intentions, at least as they enter college, would appear to be a welcome antidote, if degree-taking indeed follows.

Figure 3-4.—Science/Engineering B.S. Degrees, by Field, 1950-86



SOURCE: U.S. Department of Education, Center for Education Statistics.

Figure 3-5.—Science/Engineering B.S. Degrees, by Sex, 1950-86



SOURCE: U.S. Department of Education, Center for Education Statistics.

The implicit assumption that scientific competence in the United States is disproportionately concentrated in the 40 percent of the population represented by white males is, as one observer puts it, "a handicap that neither science nor the U.S. can any longer tolerate on economic, competitive, moral, or any other grounds."[16] Yet the gender gap in recruitment to and participation in science, reduced by two decades of gains, is in danger of widening again.[17] By now, however, strategies targeted to increase the recruitment and participation of women in science and engineering are well known (see box 3-A).[18]

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[16] Michael Heylin, "Women, Minorities, and Chemistry," *Chemical & Engineering News*, vol. 65, No. 37, Sept. 14, 1987, p. 3.

[17] Betty Vetter, "Women in Science," *The American Woman 1987-88: A Report in Depth*, D. Shavlik and J. Touchton (eds.) (Washington, DC: Women's Research and Educational Institute, 1987).

[18] Elizabeth K. Stage et al., "Increasing the Participation and Achievement of Girls and Women in Mathematics, Science, and Engineering," *Handbook for Achieving Sex Equity Through Education*, Susan S. Klein (ed.) (Baltimore, MD: The Johns Hopkins University Press, 1985), pp. 237-268. Also see Susan S. Klein, "The Role of Public Policy in the Education of Girls and Women," *Educational Evaluation and Policy Analysis*, vol. 9, No. 3, fall 1987, pp. 219-230.

Photo credit: National Institutes of Health

Females interested in scientific careers have faced strong opposition ever since science became an organized and academic activity. Slowly, the barriers to their participation are being eroded, but there are many signs that women's progress has, for the moment at least, sputtered. Renewed efforts among the existing scientific work force are needed to make science more attractive to females.

Minority College Attendance and Degree-taking in Science and Engineering

Although they constitute about 12 percent of the population (and 9 percent of the college freshmen), Blacks receive only 2.6 percent of the bachelor's degrees and 2 percent of the doctorates in science and engineering.[19] The proportion of Blacks that complete high school has increased from 10 to 70 percent in the last 40 years. Black enrollments in higher education have increased accordingly (although they are now declining, perhaps because of shifts in Federal aid from grants and scholarships to loans, which Blacks are often reluctant to assume).[20] Two-thirds of Blacks enrolled in higher education are female. Black males are shunning higher education, a talent loss of increasing proportions. Some of this loss is to the Armed Forces, which are excellent providers of technical training and also promise financial support for higher education following a period of service.[21]

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[19] A.K. Finkbeiner, "Demographics or Market Forces?" *Mosaic*, vol. 18, No. 1, spring 1987, p. 17.

[20] There are no national data to link firmly this cause with this effect, and the phenomenon may preclude the collection of information, for example, in the Department of Education's Recent College Graduate survey. See Applied Systems Inc., "Student Borrowing, Starting Salaries and Education Debt Burdens: Evidence From the Surveys of Recent College Graduates," OTA contractor report, September 1987, and discussion below.

[21] Slogans such as the Armed Forces' "It's a great place to start!" apparently have great appeal. In 1985, over 90 percent of Blacks who enlisted were high school graduates. Solomon Arbeiter, "Black Enrollments: The Case of the Missing Students," *Change*, vol. 19, No. 3, May/June 1987, p. 17. "No equivalent exists in higher education to

Box 3-A.—Recruiting Women to Science and Engineering: One Physicist's Prescription

A female physicist's observations on recruiting women to careers in science and engineering form a kind of primer on women's participation:[1]

- Positive role models, e.g, the national impact of Sally Ride, cannot be emphasized enough. "In addition to seeing women functioning as scientists and engineers on the job, students also use role models as a primary source of reassurance that a technical career can be mixed with family responsibilities."
- In any science-related activity, a "reasonably sized female peer group" provides a "critical mass." This is essential at the "most critical times when large numbers of girls turn away from considering technical careers," junior high school and at the end of the sophomore year in college, "when they are selecting a major."
- We forget that "today's culture still takes men *more* seriously" than women.

An agenda for action requires that women in science receive national attention in the form of publicizing statistics on the gap between the sexes in participation in science.

- "Newspaper editors and television producers can insist that women appear with men in news items about science and technology."
- Scholarships and internships especially for women can be offered by government agencies, academic institutions, and high-technology companies.
- The National Science Foundation can be authorized to study "the on-campus factors thought to be important in the recruitment and retention of women in science and engineering majors."
- Summer programs for high school girls can bring them to university campuses to take courses and learn about technical careers. This would be a kind of national "Science Head Start" program that Congress could delegate to the States.
- Through cooperative efforts between educational institutions and prospective employers, the alumni of these summer programs could be hired for summer jobs.

National policy, however, can be developed to support women once they enter the science and engineering work force. Among the issues that Congress should consider are these four:

1. Guidelines on maternity and paternity leave;
2. Flexible working hours, job-sharing, and home- as well as office-centered work;
3. Public and private day-care facilities of great variety; and
4. Research on interrupted careers.

These issues suggest actions that change the culture through legislation. Only the enforcement of legislation will change individual attitudes.

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[1] Most of the following text is a paraphrase of Elizabeth S. Ivey, "Recruiting More Women Into Science and Engineering," *Issues in Science & Technology*, vol. 4, No. 1, fall 1987, pp. 84-86. Direct quotes are indicated.

There have been important shifts in the institutions that Black students attend. The historically Black colleges and universities (HBCUs)[22] have been the main source of Black scientists and engineers (see box 3-B), followed by the large State universities. Most Blacks enrolled in 4-year institutions are now in traditionally white universities.[23]

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the enormously successful 'Be All That You Can Be' campaign for military recruitment." James R. Mingle, *Focus on Minorities: Trends in Higher Education Participation and Success* (Denver, CO: Education Commission of the States and the State Higher Education Executive Officers, July 1987).

[22] Historically or traditionally Black institutions refer to 105 colleges and universities so designated in 1976 by the National Center for Education Statistics and founded before 1954 for the purpose of educating Black students. These institutions are located in 19 States and the District of Columbia. Of the 100 in existence in 1984, 57 were privately controlled; the rest are under State control. Susan Hill, *The Traditionally Black Institutions of Higher Education, 1860-1982* (Washington, DC: U.S. Department of Education, 1984), p. xi.

[23] Walter R. Allen, "Black Colleges vs. White Colleges: The Fork in the Road for Black Students," *Change*, vol. 19, No. 3, May/June 1987, p. 28; Stephen Chaikind, *College Enrollment Patterns of Black and White Students* (Washington, DC: DRC, 1986); Scott Jaschik, "Major Changes Seen Needed for Colleges to Attract Minorities," *The Chronicle of Higher Education*, vol. 34, No. 13, Nov. 25, 1987, pp. A1, 31.

Box 3-B.—The National Institutes of Health Minority Access to Research Careers Program[1]

Established in 1975 by the National Institutes of Health (NIH), the Minority Access to Research Careers (MARC) Program focuses on increasing the number and research capabilities of minority scientists in biomedical fields and in strengthening science curricula at minority institutions. The object is to prepare students for careers in biomedical research. The explicit focus of the program is on improving minority students' opportunity, aspiration, and preparation for graduate study. The MARC Program offers both institutional training grants and individual fellowships: the Faculty Fellowship, the Visiting Scientist Award, the Honors Undergraduate Research Training Grant, and the Predoctoral Fellowship.

The Faculty Fellowship, the first award offered, provides opportunities for advanced research training for faculty from 4-year institutions serving predominantly minority students. Members are nominated by their institutions and may serve up to 3 years. The Visiting Scientist Award provides financial support for outstanding scientist-teachers at such colleges and universities in the hope of strengthening research and teaching in the biomedical sciences. Stipends are set on a case-by-case basis, and funding can be requested for a period from an academic quarter to 1 year. The Honors Undergraduate Research Training Grant, initiated at the suggestion of Congress and the largest component of MARC, often works in conjunction with NIH's Minority Biomedical Research Support Program. Its objective is to increase the number of well-prepared students who can compete successfully for entry into graduate biomedical programs. Training support is offered for a maximum of 5 years to carefully selected undergraduate honors students at institutions in which enrollments are drawn primarily from minority groups. The Predoctoral Fellowship, also awarded for a maximum of 5 years, targets the honors graduates and is conditional on acceptance into a biomedical Ph.D. program.

MARC provides tuition and stipend support for third and fourth year honors undergraduate students. Its specially structured curriculum includes exposure to ongoing research in the biomedical sciences, travel, administrative support, equipment purchase, and research, including summer study. From 1977 to 1984, MARC Honors has grown from $990,000 (or $700,000 in 1972 dollars) (74 trainees at 12 schools) to $4.9 million ($2.2 million in 1972 dollars) and 366 undergraduate trainees at 56 schools). Results of a 1984 evaluation and survey showed that the program was successful in keeping talented minorities in school and encouraging them to pursue research careers.

The MARC Program is continually monitored by a review committee. Site visits show that faculty members report high motivation among MARC honors students and note several examples of published research. A questionnaire sent to more than 800 former trainees indicates that three of four have enrolled in graduate or professional programs. Some critics contend that the MARC Program places too much emphasis on preparing students for research careers and ignores those with other career plans. Yet most (63 percent) MARC alumni are employed in science or engineering fields.

The institutional impact of the various MARC Programs is indicated by a definite increase in biology bachelor's degrees at MARC schools. In addition, student surveys show that the research component of the program is consistently touted as the most appealing aspect. Many maintain that they would not have continued their studies had it not been for the availability of MARC funds and the opportunities fostered by the program. The creation of role models in these graduate programs encourages the program's continued success.

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[1] Howard H. Garrison and Prudence W. Brown, *Minority Access to Research Careers: An Evaluation of the Honors Undergraduate Research Training Program* (Washington, DC: National Academy of Sciences, Institute of Medicine, Committee on National Needs for Biomedical and Behavioral Research Personnel, 1985).

HBCU enrollments and degree awards are declining, and the large State universities are not compensating for the downturn. Half of all Black students who attend college enter higher education in 2-year or community colleges. It is likely that these institutions place tiny numbers of their graduates into the science and engineering pipeline of 4-year colleges.[24]

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[24] According to a survey of 1980 high school graduates, Asian-American students were twice as likely (American Indian and white students 1½ times as likely) as Black and Hispanic students to enter 2-year colleges and later transfer to 4-year institutions. For all groups,

Photo credit: National Institutes of Health

While most Blacks in science and engineering used to come from the historically Black colleges and universities, such as Howard University in Washington, DC, an increasing proportion now enroll in traditionally white universities, including community colleges. Overall, Black enrollment in science and engineering is declining.

Most Hispanics and American Indians in higher education are enrolled in 2-year colleges. The Hispanic population is heavily concentrated in California, Texas, New York, and Florida. About 75 colleges and universities have enrollments that are over 25 percent Hispanic.[25] Institutions such as the University of Texas-El Paso, Florida International University, and the University of New Mexico have graduated large numbers of Hispanic students.[26]

Asian-American students, who are variously of Chinese, Korean, Indochinese, Filipino, Japanese, Laotian, Cambodian, Indian, and other origins, continue to do very well educationally, especially in science and engineering. One indicator of achievement is that 70 percent of Asian-American 18-year-olds take the SAT as compared to 28 percent of their age peers. Asian-Americans also tend to concentrate at top-ranking universities. The freshman classes of the Massachusetts Institute of Technology, the California Institute of Technology, and the University of California at Berkeley in the fall of 1986 were over 20 percent Asian-American, compared to 3.1 percent of all freshmen nationwide[27] (see box 3-C).

(continued from previous page)

there is a flow (of one-third to one-half as many students) in the other directions as well. See Shirley Vining Brown, *Minorities in the Graduate Education Pipeline*, Research Report of the Minority Graduate Education Project (Princeton, NJ: Graduate Record Examinations Board and Educational Testing Service, 1987), p. 5. Although no systematic field-level data are available, third-year transfers into engineering are reportedly not uncommon when an engineering institution is in close proximity to 2-year colleges that can feed it students (OTA Workshop on Engineering Education in 1997, Sept. 9, 1987; Bernard Sagik, personal communication, October 1987).

[25] *The Chronicle of Higher Education*, "Hispanics: Some Basic Facts," Sept. 16, 1987, p. A36. In 1987, 60 U.S. institutions founded the Hispanic Association of Colleges and Universities. Based on a criterion of at least 25 percent Hispanic enrollment, 100 institutions are expected to qualify by the year 2000. See Cheryl M. Fields, "Demographic Changes Bring Large Hispanic Enrollments to Over 60 Institutions," *The Chronicle of Higher Education*, Oct. 7, 1987, p. A40.

[26] Richard C. Richardson, Jr. et al., "Graduating Minority Students," *Change*, vol. 19, No. 3, May-June 1987, p. 24.

[27] Evidence of the superior academic performance of Asian-American students has been described recently in *Time*, the Sunday *New York Times Magazine*, and the *Los Angeles Times Magazine* in stories alleging discrimination against Asian-American students in admissions to U.S. colleges and universities, and their perception as a "nondisadvantaged" minority. See Green, op. cit., footnote 8; *Manpower Comments*, vol. 24, No. 10, December 1987, pp. 14-15.

Box 3-C.—Asian-Americans in Science and Engineering: Perceptions and Realities

Stereotypes abound about the intelligence and educational achievements of Asian-American children. A closer look suggests that reality is far more complicated than perceptions, though a lack of research on the interaction of country of origin, social class, and family structure with educational success inhibits understanding of Asian-American participation in the science and engineering work force.

The whiz-kid image fits many of the children of Asian immigrant families who arrived in this country in the late 1960s and early 1970s, following passage of a 1965 law liberalizing immigrant quotas. Most of these immigrants came from Hong Kong, South Korea, India, and the Philippines. And the image fits many children of the more than 100,000 Indochinese (primarily Vietnamese) immigrants who arrived in this country following the end of the Vietnam War in 1975.[1]

Both of these groups included mostly middle- to upper-income professional people who were fairly well-educated and who passed on to their children an abiding interest in education and a strong work ethic.

For thousands of other Asian-Americans—a high percentage of the 600,000 Indochinese refugees who fled Vietnam, Laos, and Cambodia in the late 1970s—the problems are far different. Many of this recent wave of refugees lived in poor surroundings in their homelands. They came to the United States with few skills and little English, have a tough time finding a decent job, and often share housing with relatives. Their children find it difficult to learn; some are attracted to drugs and gangs; many drop out of school.

There may be both a generational and a class factor influencing Asian-American students' orientation to education. There is also a geographical dimension: over one-third of Asian-Americans reside in California and another 22 percent in Hawaii and New York combined.

Asian-American college-bound seniors have the highest high school grade point averages and degree aspirations. They do especially well in mathematics courses, which may account more than their verbal or social skills for their attraction to science and engineering. Asian-Americans take more, and score higher on, Advanced Placement examinations offered in science and mathematics. They also excel in the mathematics portion of the Scholastic Aptitude Test. In 1985, Asian-American college-bound seniors were twice as likely as other students to plan an undergraduate major in engineering.[2] Because their preparation is better and their attrition less than other groups, Asian-American students succeed in higher education at all degree levels.

In 1986, there were over 225,000 Asian-American scientists and engineers representing about 5 percent of the total science and engineering work force, compared to 2 percent of the overall U.S. work force.[3] The Asian-American contribution to U.S. science and engineering is indisputable. But no *single* ethnic group will compensate for the declining numbers of white students planning careers in science and engineering, despite the growth in minority populations over the next two decades.

As for the perception of Asian-American students, the words of a resource teacher with the St. Paul, Minnesota, school system's Multicultural Center are instructive:

> We encourage our teachers not to look at minority children as having to fit into one mold. Instead we try to point out that each child brings to the classroom a different set of cultural characteristics—differences in values, in home life, in economic circumstances.[4]

Once these immigrant groups assimilate, it is uncertain how the differences we now observe will be sustained, and what will affect their future educational achievements, including their contributions to American science and engineering.

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[1] This and the quotes that follow are from Bill Fischer, " 'Whiz Kid' Image Masks Problems of Asian Americans," *NEA Today*, vol. 6, No. 8, March 1988, pp. 14-15.

[2] National Science Foundation, *Women and Minorities in Science and Engineering*, NSF88-301 (Washington, DC: January 1988), pp. 43-45.

[3] Also, in 1985, over 34,000, or 8 percent, of employed doctoral scientists and engineers were Asian; one-third of them were non-U.S. citizens. For other field, labor market, and career pattern comparisons see ibid., pp. 22-24 and appendix tables.

[4] Fischer, op. cit., footnote 1, p. 15.

PRODUCTIVE ENVIRONMENTS—UNDERGRADUATE ORIGINS OF SCIENTISTS AND ENGINEERS

Variety among higher education institutions distinguishes the United States from other countries and contributes enormously to the education system's success and ability to reach so many students. Institutions include vast State universities and colleges (obliged to admit qualified resident high school graduates), engineering institutes akin to industrial training schools, and research universities of international repute. Private liberal arts colleges, historically Black institutions, and an array of others complete the picture.

Each type of institution serves a different clientele and has a particular local, State, or national context. Community colleges, predominantly county-based, train skilled workers and serve, for a few, as stepping stones to full baccalaureate programs. Liberal arts colleges are rooted in the classical notion that exposure to the great books and works in all disciplines is the way to instill democracy and higher-order thinking in the citizenry.

Institutions also vary in their relative emphasis on teaching and research, and on undergraduate and graduate teaching. One group of institutions, research universities, specializes in research and graduate teaching. Another group, a subset of the liberal arts colleges, specializes in undergraduate education, but does research as well. Some institutions are oriented primarily or exclusively to certain populations such as Blacks or women. Each type of institution, with its unique role, contributes to the strength of the entire higher education system.

There is competition among types of institutions and within the types themselves. Institutions compete for Federal and industry research funds, for talented students and faculty, and for equipment and facilities support. Most science and engineering undergraduates are produced by the major research universities, State institutions, and the private liberal arts colleges. From the point of view of the future science and engineering research work force, an important measure of the success of the education provided by these environments is the number of their graduates that go on to earn Ph.D.s in science and engineering.

Graduates who later earn Ph.D.s in science and engineering come from a limited number of undergraduate institutions. Ranked by the absolute number of their alumni that later receive Ph.D.s in science and engineering, 100 schools supply 40 percent of all students who receive doctorates. Four out of five of these top 100 undergraduate institutions are private.[28] Of these institutions, large degree-granting institutions (the "research universities") have the highest output of bachelor's graduates who go on to earn science and engineering Ph.D.s.

A group of about 50 private liberal arts colleges, however, has claimed to be especially productive, and accordingly, deserving of funding for research equipment and teaching.[29] These "research colleges" claim that their traditional small scale, emphasis on research experiences for undergraduates, and focus on individual students are major contributors to the eventual production of Ph.D.s in science and engineering.[30] For example, their students are encouraged to work with faculty members on current scientific research and to become full participants in research teams. A subset of this group, such as Bryn Mawr, Mt. Holyoke, and Smith, focuses on educating women and claims to be particularly productive of female scientists.

By looking at an estimate of the proportion of each institution's baccalaureate graduates in all fields that have gone on to gain Ph.D.s in science and engineering, OTA finds that some liberal arts colleges as well as universities that specialize in technical education are unusually productive of future Ph.D. scientists and engineers, when allowance is made for the size of these colleges (see figure 3-6). A large proportion of the graduates of these environments also subsequently join the research work force.[31]

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[28] This finding is based on an analysis of four baccalaureate cohorts dating from academic years 1950-51 to 1965-66. Degree totals were extracted from the Center for Education Statistics' annual *Earned Degrees Conferred*, and linked to the National Research Council's Doctorate Records File to calculate institutional productivity rankings through 1979. A 10-year lag from baccalaureate to Ph.D. award was used to create this indicator of institutional productivity. The methodology and various rankings are contained in Betty Maxfield, "Persistence in Higher Science and Engineering (S/E) Education: S/E Baccalaureate to S/E Doctorate Productivity of U.S. Baccalaureate-Granting Institutions," OTA contractor report, September 1987.

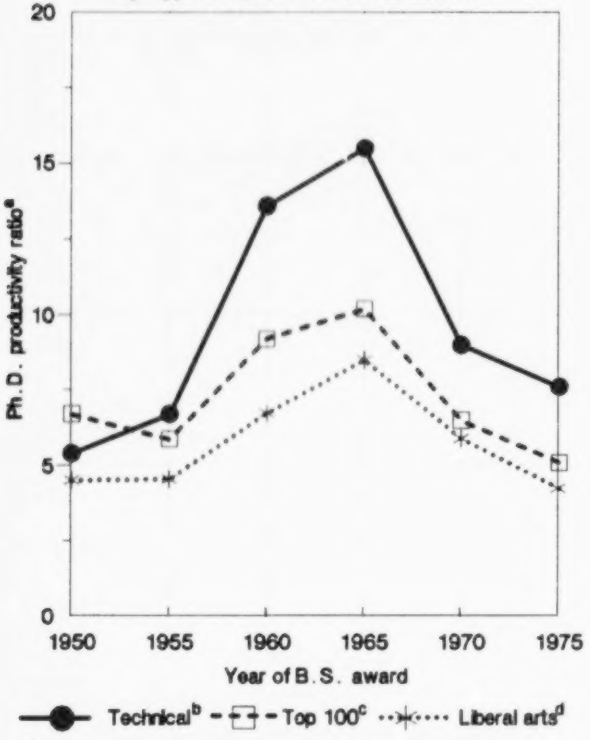
[29] In 1985, these colleges undertook a self-study: David Davis-Van Atta et al., *Educating American Scientists: The Role of the Research College* (Oberlin, OH: Oberlin College, May 1985). A Second National Conference on "The Future of Science at Liberal Arts Colleges" in 1986 resulted in another report: Sam C. Carrier and David Davis-Van Atta, *Maintaining America's Scientific Productivity: The Necessity of the Liberal Arts Colleges* (Oberlin, OH: Oberlin College, March 1987). Together, they are known as the Oberlin Reports. Although the labels "research colleges" and "science intensives" have been applied, they are not embraced even by members of the 50 colleges. Also, another 50 colleges probably share the characteristics of those included in the Oberlin Reports (see app. A). Thus, OTA's use of the term "research colleges" refers to about 100 private liberal arts colleges where, historically (and ironically), teaching has been especially valued.

[30] A quarter-century ago, liberal arts colleges were found to be among the 50 most productive institutions of higher education. R.H. Knapp and H.B. Goodrich, "The Origin of American Scientists," *Science*, vol. 133, May 1951, pp. 543-545. This finding was later confirmed by M.E. Tidball and V. Kistiakowsky, "Baccalaureate Origins of American Scientists and Scholars," *Science*, vol. 193, August 1976, pp. 646-652.

[31] During the 1970s, when single-sex colleges either merged or began admitting sizable numbers of students of the opposite sex, 2 percent of women baccalaureates from coeducational institutions went on for a science or engineering Ph.D. compared to 10 percent of the graduates of women's colleges. See M.E. Tidball, "Baccalaureate Origins of

(continued on next page)

Figure 3-6.—Science/Engineering Ph.D. Productivity, by Type of B.S. Institution, 1950-75



[a]Percent of all B.S. graduates who later got science/engineering Ph.D.s. The bulge in science/angineering Ph.D. productivity tracks the increase in Federal fellowship (and R&D) spending during the 1960s.

[b]Fifteen institutions with an emphasis on science/engineering and that send a large proportion of their students on to science/engineering Ph.D.s.

[c]The 100 institutions of all types that have the highest productivity ratios for science/engineering Ph.D.s.

[d]The 50 liberal arts colleges that participated in the Second National Conference on "The Future of Science at Liberal Arts Colleges" at Oberlin, June 1986. These colleges are also known as "research colleges" due to their emphasis on undergraduate and faculty research.

SOURCE: Betty D. Maxfield, OTA contractor report, 1987.

Figure 3-6 also reveals a peak in the 1960s that can be traced (see below) to the sharp rise in Federal fellowship and academic research funding in the early 1960s, followed by decline from the late 1960s into the 1970s. The bulge in baccalaureates going on for science and engineering Ph.D.s appears in all types of institutions, but is pronounced in the research-oriented ones and those receiving the most Federal dollars.

The quality of students recruited and enrolled in an institution, of course, is related to the number and quality of those who emerge with baccalaureate degrees. The education provided by the research colleges is very costly; most of the costs are borne by students and their families.[32] These colleges are highly selective in admitting students, but make great efforts to ensure students' success by offering considerable personal attention and support. The institutional environment clearly matters.[33] Elements of students' experiences in the research colleges that encourage pursuit of the Ph.D., such as early research experience, the emphasis that such schools place on teaching, and their small student-faculty ratios, could be replicated at other institutions.[34] **OTA concludes that to increase numbers of Ph.D. scientists and engineers, it would be worth studying techniques used by research colleges and encourage other institutions to adopt similar strategies and values.**

(continued from previous page)
Recent Natural Science Doctorates," *Journal of Higher Education*, vol. 57, No. 6, November/December 1986, pp. 606-620. In the analysis reported here, total baccalaureate output, not numbers of males and females separately, defined the productivity of institutions. Except for the predominantly women's colleges, OTA has not determined which institutions sent large numbers of women on for Ph.D.s; only the top Ph.D. producers for both sexes combined have been identified. (Elizabeth Tidball, personal communication, Dec. 16, 1987.) Also note that the predominantly women's colleges and historically Black colleges and universities serve more homogeneous populations than other types of institutions. Numerical comparisons with coeducational, largely white institutions do not capture this special kind of productivity. See, for example, Michael T. Nettles et al., "Comparative and Predictive Analyses of Black and White Students' College Achievement and Experiences," *Journal of Higher Education*, vol. 57, No. 3, May-June 1986, pp. 289-318. Institutional-level measurement is at best a crude proxy for the climate that fosters educational success of those who experience it, and perhaps contributes to students' later persistence to the Ph.D.

[32] Carrier and Davis-Van Atta, op. cit., footnote 29.

[33] Robert S. Eckley, "Liberal Arts Colleges: Can They Compete?" *The Brookings Review*, vol. 4, No. 4, fall 1987, pp. 31-37. Not only is there lack of agreement on the definition of and criteria for measuring student "quality," but ". . . there are no detailed and comparable national data on student performance at the postsecondary level. At best, only crude estimates can be made of the quality of subgroups in the graduate talent pool by examining trends and characteristics of the applicants taking such tests as the GRE [Graduate Record Examination]." Brown, op. cit., footnote 24, p. 7. Also see T.W. Hartle, "The Growing Interest in Measuring the Educational Achievement of College Students," *Assessment in American Higher Education*, C. Adelman (ed.) (Washington, DC: U.S. Department of Education, 1986).

[34] Alexander W. Astin, *Four Critical Years* (San Francisco, CA: Jossey-Bass, 1977), esp. pp. 44, 89. These elements are central to some other highly productive (small technical) institutions such as Harvey Mudd and the California Institute of Technology. Like the Massachusetts Institute of Technology and other research universities, these institutions emphasize undergraduate research, indeed often require a research thesis for graduation. See, for example, Janet Lanza, "Whys and Hows of Undergraduate Research," *BioScience*, vol. 38, No. 2, February 1988, pp. 110-112.

ENGINEERING EDUCATION

Key Questions

- How well does the preparation of new engineering graduates satisfy the needs of industry?
- What are the effects of the huge rise in the number of foreign graduate students on engineering employment and engineering teaching?
- Why, after more than a decade of growth, has the participation of women in engineering begun to decrease in the last few years?
- What effects have changing enrollments in computer science had on universities and on employment markets?
- What role does and might the Federal Government have in engineering education?

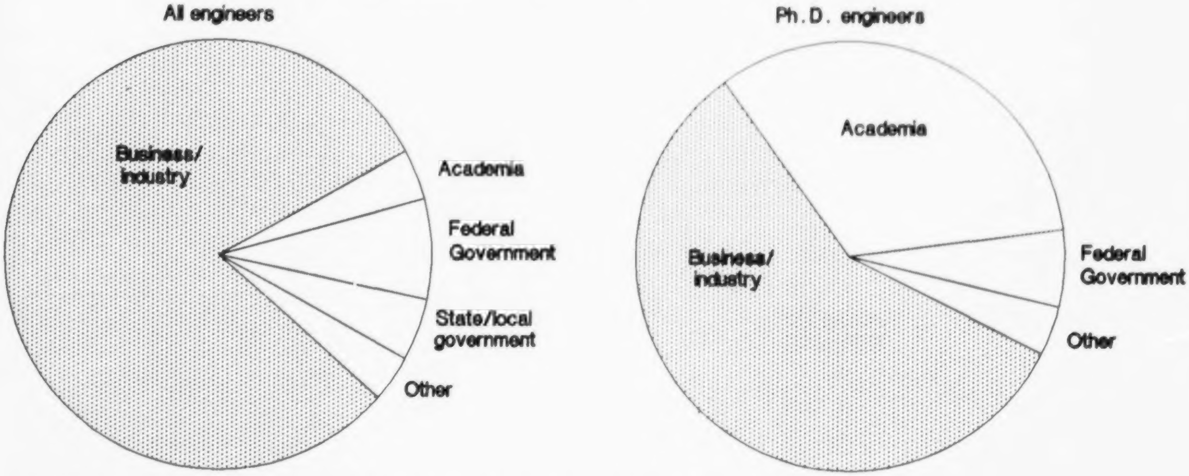
Key Findings

- Most engineers are employed in industry. Industrial demand—both civilian and defense—for baccalaureate engineers is a powerful magnet drawing students into engineering programs.
- The existing stock of engineers and technicians is versatile and can adapt its skills, but at a cost to employers and educational institutions alike.
- Engineering education needs to balance the curricular tug-of-war between the practice-oriented pull of industry and the research- and analysis-oriented push of universities.
- The complexity and cost of equipment for teaching engineering is high and rising dramatically, and many engineering schools are unable to keep up.
- Foreign graduate students have been attracted by the quality of American engineering education and have compensated for the dearth of U.S. citizens who are interested in graduate school.
- The increasing national attention to competitiveness portends an increasing Federal role in engineering education.

Engineering differs radically from science. As a profession, it is more oriented to business and problem-solving, it is highly sensitive to technological change, and it accepts the baccalaureate as the first professional degree. All these differences shape the engineering education system and its curriculum. Because students are trained for professional practice, engineering curricula normally must be accredited by the Accreditation Board for Engineering and Technology.

About 80 percent of engineers are employed in industry (see figure 3-7). Even at the high school level, employment considerations, especially per-

Figure 3-7.—Where Engineers Work, 1986



SOURCE: National Science Foundation, Science Resources Studies, *Science and Engineering Personnel.*

ceived entry-level salary, may play a larger role in students' career intentions than they do in the plans of those intending to major in science.[35] These same factors, along with engineering's acceptance of the baccalaureate instead of the doctorate, make the engineering education system particularly responsive to changes in the job market. That system can accommodate large curricular changes and shifts of interest, both in the absolute size of demand and in the balance between different fields, over periods of 3 to 5 years.

Engineering and computer science have been the fastest growing areas of study in science and engineering since the early 1970s. Engineering bachelor's degrees rose from 4.5 to 8 percent of all bachelor's degrees between 1975 and 1985.[36] Engineering schools' ability to accomplish this doubling of production has been impressive. Growth in these fields has now stopped, as the job market (particularly in the electronics and computer industries) has lost some of its steam, and as the supply of 18-year-olds has begun to decline.

The master's degree has long been an important final degree for engineering; seven times as many master's degrees are awarded in this field as Ph.D.s.[37] Especially when it involves business and managerial components, the master's is becoming a valued professional degree. Meanwhile, engineering doctorates, in decline since their peak in the early 1970s, have increased over the past few years, largely because of the influx of foreign graduate students into U.S. engineering schools.[38]

Industrial and academic demand for Ph.D.s in engineering is strong. Yet there is pressure to create separate research and teaching streams in graduate school, for the doctoral route feeds two different employment markets: industrial R&D and university faculty. After a downturn in the 1970s, engineering Ph.D. awards are slowly rising, but represent less than 20 percent of all Ph.D. awards in science and engineering.[39]

Balancing Analysis and Practice in Engineering Curricula

Engineering enrollments and market demand aside, many see weaknesses in engineering curricula and teaching methods. There has always been a tug-of-war between industry's focus on immediately applicable skills and the university's commitment to fundamental knowledge and understanding. There is some evidence that engineering education has been skewed by the pattern of Federal research funding in the 1960s. Critics have charged that the research culture of engineering schools emphasizes theory and research, failing to teach solutions to problems of design, production, and manufacturing with which most working engineers must deal.[40]

An important related issue is the extent to which students should be exposed—on campus and off in neighboring industry—to up-to-date engineering equipment and technology in college. Outdated facilities and equipment are a growing problem throughout science and engineering education, in teaching and research, but the problem is most severe in engineering.[41]

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[35] Carolyn M. Jagacinski et al., "Factors Influencing the Choice of an Engineering Career," *IEEE Transactions on Education*, vol. 28-E, No. 1, February 1985, pp. 36-42.

[36] Engineering Manpower Commission, *Engineering and Technology Degrees* (Washington, DC: American Association of Engineering Societies, published annually). Unless otherwise noted, engineering degree data are from the Engineering Manpower Commission. The Commission data at all degree levels tend to be slightly higher than data reported by the National Research Council and the U.S. Department of Education's Center for Education Statistics, but follow a similar pattern.

[37] Ibid.; U.S. Department of Education, op. cit., footnote 1, p. 184. In addition, at least 20 percent of master's-level engineers are employed in the defense industry (National Science Foundation, unpublished data).

[38] Elinor Barber and Robert Morgan, "The Impact of Foreign Graduate Students on Engineering Education," *Science*, vol. 236, No. 4797, Apr. 3, 1987, pp. 33-37; National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook*, NSF 86-305 revised (Washington, DC: 1987).

[39] National Research Council, *Survey of Earned Doctorates* (Washington, DC: published annually). Ph.D.s in engineering research are discussed along with the Ph.D. science work force in the section that follows on "Graduate Education."

[40] These observations on tensions and trends are based on Steven L. Goldman, "A History of Engineering Education: Perennial Issues in the Supply and Training of Talent," OTA contractor report, September 1987. Also see National Research Council, *Engineering Education and Practice in the United States: Engineering Infrastructure Diagramming and Modeling* (Washington, DC: National Academy Press, 1986); National Academy of Engineering, *Engineering Undergraduate Education* (Washington, DC: National Academy Press, 1986).

[41] Independent surveys—by the National Science Foundation, the National Society of Professional Engineers, and OTA—of heads of engineering departments at major universities all support this conclusion. See *Chemical and Engineering News*, "Engineering Equipment Needed," vol. 66, No. 1, Jan. 4, 1988, p. 19. The National Science Foundation

Photo credit: University of Tulsa and The Chronicle of Higher Education

The majority of engineers work in industry, and universities are expected to train engineering students using equipment similar to that which they will use in industry. Here, a student at the University of Tulsa, Oklahoma, inspects an oil well drill bit that is part of the university's full-scale research drill rig. Much university engineering equipment is outdated, and replacements are increasingly expensive.

Computers for design, sophisticated production machinery, and other equipment have revolutionized practice in many fields of engineering, and universities must teach their students about current technology. It is increasingly difficult for engineering schools to finance the continual upgrades in equipment and facilities required for high-quality engineering teaching. This problem is especially severe in the 200 comprehensive schools (those below the top 50 or so, as measured by the number of engineering degrees awarded), which produce about half the B.S. engineers.

There are a variety of ways to expose students to new engineering technology and the work conditions of real engineers, without attempting to match industrial facilities. Some of the technology (for example, that of computer-aided design) can be simulated by computers. Cooperative work-study arrangements with industry, part-time employment, and summer internships are also helpful.[42] These programs give students the first-hand experience of actual engineering practice. The use of adjunct faculty borrowed from industry is another way to impart up-to-date knowledge of industrial methods.

The Transition to Work

Employers customarily train young engineers, normally hired with only bachelor's degrees, to meet the particular demands of their firms. This on-the-job training socializes engineers and overcomes what many in industry see as an overly theoretical bias imparted by engineering schools. Employers, by and large, do not expect new B.S. engineers to be fully competent for 6 to 12 months after hiring.

Employers are finding that the speed of change in engineering technology recently has left engineering schools further and further behind in exposing students to current techniques and working conditions. This development places a growing training burden on industry, and both universities and companies are adjusting their methods accordingly. Part-time jobs, internships, and cooperative work-study programs in industry are all regarded as excellent opportunities to orient students to the working conditions, culture, and technology of actual engineers.

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report observes that, "Engineering may be a field that has been running hard just to stay even and that soon may have increasing difficulties in maintaining current stocks of basic research equipment." National Science Foundation, *Academic Research Equipment in the Physical and Computer Sciences and Engineering: 1982 and 1985—Executive Summary*, SRS 87-D6 (Washington, DC: October 1987), p. 9.

[42] Cooperative education—student work in industrial or corporate settings—is particularly important for providing role models and career guidance. Engineering cooperative graduates, like other cooperative students, tend to receive higher salaries and better jobs after graduation, yet they are no less likely than other engineers to enter graduate school. See Richard P. Nielsen et al., *An Employer's Guide to Cooperative Education* (Boston, MA: National Commission on Cooperative Education, 1987).

Industry, which has a long tradition of on-the-job training for young baccalaureate engineers, has in these ways expanded its influence on the engineering schools in recent years. The Federal Government, by promoting joint industry-university R&D programs and by establishing federally funded engineering centers on campuses, is encouraging this more expansive role.[43]

Another continuing tension is over the length of the engineering curriculum. For decades, the expanding technical content of many engineering fields has created pressure to institute 5-year engineering programs in place of the traditional 4-year course. A few institutions have done so, but more have abandoned this experiment. One issue is whether this additional coursework should consist of technical electives or "liberal studies." The point may be moot; industry enthusiasm for these programs is lukewarm, since on-the-job training of young engineers can more easily be tailored to firms' particular needs.

Engineering Attracts Few Women and Minorities

The places of women and minorities in engineering education, as in the engineering work force, show continuing inequities (see table 3-2). The proportion of women in engineering undergraduate programs, after 15 years of steady gains, during which they rose from 1 to 15 percent of the bachelor's degrees awarded annually, leveled off in 1985 and dropped in 1986.[44] Freshman women's degree intentions indicate that they will not continue their progress toward equal representation in the near future; interest is actually slumping. Women represent only 3 percent of the engineering work force. They concentrate in chemical and industrial engineering, and are less well represented in high-growth fields such as electrical engineering.[45]

Table 3-2.—Engineering Degrees, by Level, Sex, and Race/Ethnicity, 1986

	Percent of degrees		
	B.S.	M.S.	Ph.D.
Women	14.3	11.9	6.7
Black	2.7	1.5	0.5
Hispanic[a]	2.8	1.4	1.0
Asian/Pacific	6.2	7.4	6.2
American Indian	0.2	0.1	—
All minorities	11.9	10.5	7.8

[a] Includes degrees awarded at the University of Puerto Rico. Excluding this university drops the Hispanic B.S. rate to 2.4 percent.

SOURCE: Engineering Manpower Commission, 1987.

Blacks and Hispanics, too, earn a small fraction of the degrees awarded in engineering. Blacks, in 1986, received less than 3 percent of the engineering baccalaureates, a similar share as in 1979. Hispanics, with about 7 percent of the U.S. population, received about 2.4 percent of the engineering baccalaureates. These modest levels of participation by both groups are exacerbated by high attrition; about half of the Hispanics and one-third of the Blacks who enroll in engineering as freshmen complete their undergraduate degrees. (The national average is 30 to 40 percent. Also, few opportunities are given to late entrants, owing to the sequential nature of the required preparation.) Intervention programs, such as the Minority Engineering Program now operating throughout the California State University system, have increased student persistence to the baccalaureate.[46]

Foreign Citizens in Graduate Engineering Education

The most fundamental recent development in graduate engineering education is the large foreign influence in U.S. engineering schools. Engineering and some fields of science, such as mathematics and physics, have long had significant numbers of foreign-born faculty, most of whom have become naturalized citizens. The influx of foreign students during the last decade, though, is of an unprecedented scale. More than half the engineering students in American graduate programs today are foreign citizens, most of whom hold temporary visas that call for eventual return to their native lands. Fewer and fewer U.S. citizens are willing to forego the lucrative salaries that new baccalaureate engineers (and some scientists) can obtain, in favor of several years of graduate student poverty that will yield them a few thousand dollars more in annual starting salary. Today, more engineering Ph.D.s are awarded to foreign-born students than U.S. citizens (figure 3-8). University faculties are even more heavily weighted toward non-U.S. citizens, especially at the assistant and associate professor levels.[47] While half of foreign engineering graduate students plan to join the U.S. work force, about 60 percent of foreign students obtaining Ph.D.s in the United States remain here (see box 3-D).[48]

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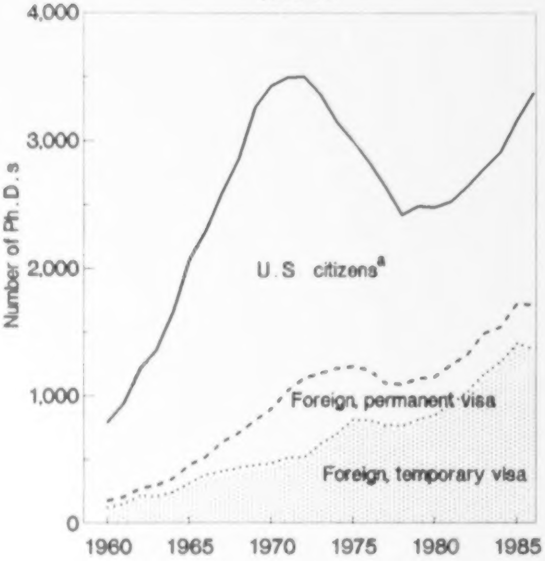
[43] Nam P. Suh, "The ERCs: What We Have Learned," *Engineering Education*, vol. 78, No. 1, October 1987, pp. 16-18; Don E. Kash, *The Engineering Research Centers: Leaders in Change* (Washington, DC: National Academy Press, 1987); Debra M. Amidon Rogers, "Meeting the Global Challenges of a New Era," *Engineering Education*, vol. 78, No. 4, January 1988, pp. 222-223.

[44] Vetter, "Women's Progress," op. cit., footnote 14, pp. 4-5.

[45] Office of Technology Assessment, op. cit., footnote 6, pp. 69-79.

[46] For a review of national minority engineering programs, including the institutions most productive of minority engineers, see *Black Issues in Higher Education*, "Special Report: Engineering Education," vol. 4, No. 15, Oct. 15, 1987, pp. 9, 12-15. Also see Edmund W. Gordon et al., *A Report to the Field: A Descriptive Analysis of Programs and Trends in Engineering Education for Ethnic Minority Students* (New York, NY: National Action Council for Minorities in Engineering, 1987).

Figure 3-8.—Engineering Ph.D.s, by Visa Status, 1960-86



[a]Includes unknown citizenship (currently about 8 percent of total)

SOURCE: National Research Council, *Survey of Doctorate Recipients*.

Box 3-D.—Immigration Policy and Practice: How Foreign Nationals Enter the U.S. Science and Engineering Work Force

Foreign nationals enter the U.S. science and engineering work force by several paths. Knowledge of the different paths of immigration and the requirements and regulations for each is important for guiding policy on the flow of foreign scientists and engineers into and out of the United States. Immigration is controlled by laws and by rules and regulations set by the Immigration and Naturalization Service (INS), the Department of Labor, and the Department of State.[1] Most immigration policy is set by INS, although the Department of State actually issues all visas. Immigration into the United States falls into two broad categories: immigrants exempt from limits (for immediate family and refugees) and immigrants subject to quotas (that give preference, for example, to distant family members and workers with needed skills).

Temporary Entry—Students and Temporary Workers

Like all immigrants, many immigrant scientists and engineers first enter the United States as temporary workers or students (see table and diagram below). Foreign science and engineering students, visitors, and temporary workers may enter the United States without limitation, and contribute significantly to U.S. research during the years they are here. It is widely believed that about half of foreign science and engineering students stay in the United States for at least a few years after graduation in order to work, and many of these stay for many years or permanently.[2] The university route to immigration has become more important relative to direct immigration into the work force since 1976, when immigration law changes made it difficult for foreign workers to enter without a firm job offer.

Most foreign students enter the United States on F-1 temporary student visas, usually issued for the entire anticipated duration of study. Some enter on J-1 exchange visitor visas, which usually require that the visitor

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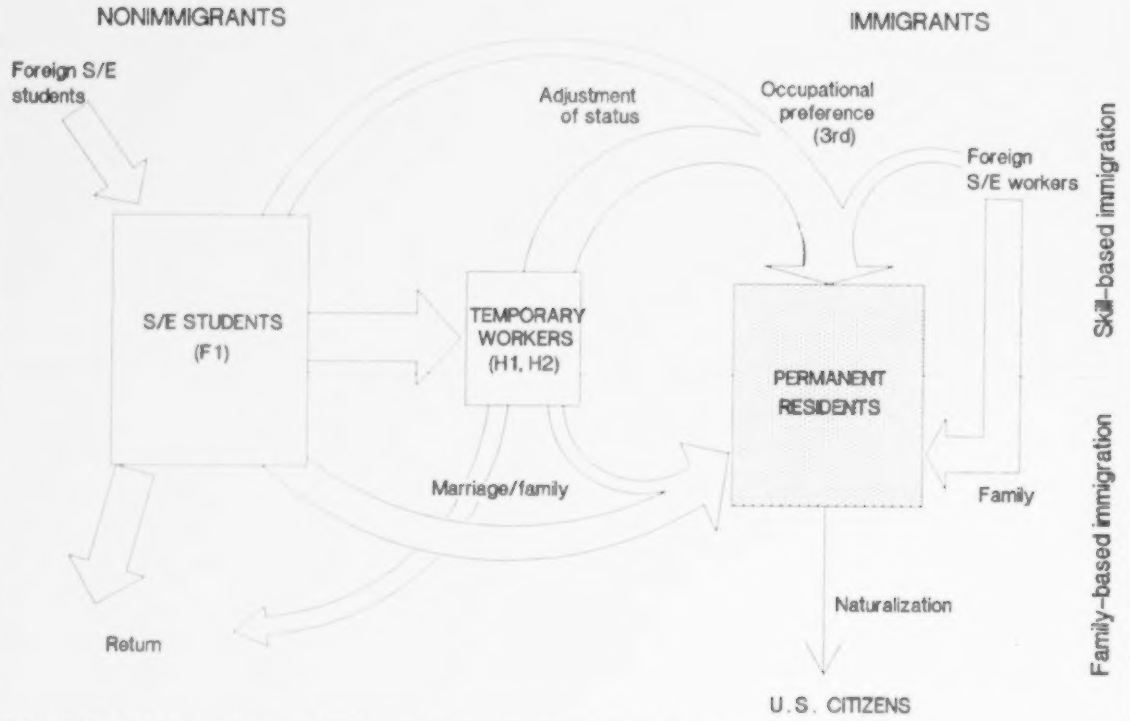
[47] Paul Doigan and Mack Gilkeson, "Engineering Faculty Demographics: ASEE Faculty and Graduate Student Survey, Part II, *Engineering Education*, vol. 77, January 1987, p. 208.

[48] National Science Foundation, *National Patterns of Science and Technology Resources* (Washington, DC: 1986), p. 25; U.S. General Accounting Office, *Plans of Foreign Ph.D. Candidates: Plans of U.S. Trained Foreign Students in Science/Engineering*, GAO/RCED-86-102FS (Washington, DC: U.S. Government Printing Office, February 1986), p. 3; National Research Council, *Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues* (Washington, DC: National Academy Press, 1988), p. 2; National Science Foundation, op. cit., footnote 38.


NONIMMIGRANTS
IMMIGRANTS
Foreign S/E students
Adjustment of status
Occupational preference (3rd)
Foreign S/E workers
S/E STUDENTS (F1)
TEMPORARY WORKERS (H1, H2)
PERMANENT RESIDENTS
Marriage/family
Family
Return
Naturalization
U.S. CITIZENS
Skill-based immigration
Family-based immigration

SOURCE: Office of Technology Assessment, 1988, based on data from the Immigration and Naturalization Service

or student return to his or her native land before seeking permanent residence in the United States. A small number of foreign students are already permanent residents of the United States on the basis of family ties, and require no further permission to be students. There are no quotas on student visas, and essentially all student visa applications are approved. (Applicants must have been admitted to a U.S. institution and show 1 year of available funds and access to support for the duration of their studies; foreign students may not work, except on campus.) About half of foreign students major in science or engineering.[1]

When a student graduates, he or she may apply to INS for a 1-year extension for "practical training" in their field. Such extensions are almost always granted. During this period foreign students may hold paying jobs. Foreign scientists and engineers may also stay temporarily in the United States under a different visa category, H visas, for temporary workers of distinguished ability (H-1 visa), with needed skills (H-2), or trainees (H-3). Most such temporary workers have already been in the United States as students, and adjust their visa status upon application to INS; others come directly from their home country. There are several subclasses of temporary workers. Most scientists or engineers work under H-1 visas, for temporary workers who are professionals (which includes most science or engineering graduates) or of distinguished merit or ability. To be admitted to H-1 status, an applicant must have a job offer and the prospective employer must demonstrate to the INS that the individual has special skills and that the job that the individual will undertake requires such skills. A few scientists and engineers work under H-2 visas, for which the employer must establish for INS that there are no U.S. citizens willing and able to take the position, and that admission of the individual will not adversely affect labor markets. The individual does not necessarily have to be of extraordinary merit. The H-1 and H-2 visas can normally be renewed annually, under current INS policy up to a maximum of 5 years. There is no limitation on the number of H-1 and H-2 visas that may be issued annually. It is usually quite easy for a foreign science or engineering student to adjust to temporary worker status.

Immigration

Foreign nationals can work temporarily in the United States under either the F-1 practical extension or the H-1 and H-2 status, but cannot reside permanently in the United States on these visas. There are two routes by which foreign nationals can become permanent residents, a status which allows them to work and live in a manner equivalent to U.S. citizenship. (Achieving permanent residence is the major hurdle for foreign citizens. Permanent residents are for most purposes the same as U.S. citizens; naturalization is merely validation.)

The first route is marriage or being part of the immediate family of a U.S. citizen. In this case, permanent residence is granted for family reunification and entry is granted without reference to the person's skills. There is no limit on the number of people admitted on this basis. Most scientists and engineers who achieve permanent residence do so through this path.

About 30 percent of the scientists and engineers that become permanent residents do so on the basis of occupational preferences, and the number of people admitted on this basis is controlled by annual worldwide quotas set by INS. Scientists and engineers most commonly enter under the third preference, for professionals of particular skills. Some enter under sixth preference for skilled or unskilled workers. For admission under the third or sixth preference, the applicant's employer is required to petition the Department of Labor to show that admission of the applicant would not adversely affect U.S. workers similarly employed and that that there are no U.S. citizens with the skills or the inclination to take the job in question. A very few scientists and engineers of professional reknown and international reputation enter under Schedule A, group II—a select list of occupations for which the Department of Labor (DOL) has already determined that there is a shortage of U.S. citizens. (Although DOL makes the list, INS decides who qualifies for immigration under Schedule A. Engineers used to be, but are no longer, on Schedule A.) Following approval by the Department of Labor ("labor certification"), the applicant then must petition the INS, which considers the application on the basis of geographic and other quotas.

Although immigration policy governs the entry and exit of foreign scientists and engineers, other influences affect the pressure on that immigration system. Federal and university policies on tuition and awarding various forms of support to foreign citizens affect the attractiveness of study at U.S. universities, although most foreign students bring substantial support with them. Federal, State, and corporate employment policies, particularly for defense-related work, shape the job market for foreign nationals. And political and economic conditions in foreign countries drive the flow of their citizens abroad.

The system of temporary and permanent immigration to the United States has evolved gradually over time and has been amended to reflect changing priorities. Among the many goals of immigration policy are promoting tourism and increasing international exchange and understanding; unifying and reunifying families; encouraging talented people to bring their skills to the United States; offering a safe haven to refugees from from war; protecting American workers; and controlling the national origins of immigrants to the United States. Since immigration practices are often built around achieving each goal separately, these goals sometimes conflict.

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[1] The Immigration and Nationality Act of 1952, as amended by various laws, particularly the Immigration and Naturalization Act of 1965 (which ended national origin quotas, created preference groups, and introduced labor certification), the Eilberg Act of 1976 (which tightened labor certification requirements), and the Immigration Reform and Control Act of 1986. The lead Federal agencies have considerable discretion in setting policy. The immigration system is large, complex, and fairly individualistic; there are always minor exceptions to general practice.

[2] Michael G. Finn, Oak Ridge Associated Universities, *Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982*, (Oak Ridge, TN: June 1985), cited in National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook*, NSF 86-305 revised (Washington, DC: 1986), p. 39.

[3] Institute for International Education, *Open Doors 1985/86* (New York, NY: 1986).

The high quality of foreign-born students and faculty is not at issue. Furthermore, without them, many graduate engineering programs would have to close their doors, and engineering faculty would be scarce. However, worry about language problems and the impact of cultural differences on the future engineering work force are warranted. Some women engineering students, for example, have reported discrimination by foreign faculty and graduate teaching assistants that exceeds the residual sexism they encounter in the predominantly male culture of engineering education.[49]

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[49] T.A. Heppenheimer, "Engineering Education: Stability Under Strain," *Mosaic*, vol. 18, No. 1, spring 1987, pp. 18-25; National Research Council, op. cit., footnote 48, p. 8.

Photo credit: California Institute of Technology

Foreign citizens who attend American universities to study science and engineering are generally regarded as excellent and hardworking, and many stay in the United States and join the work force. However, the high proportion of foreign citizens in some fields, particularly engineering and mathematics (and to a lesser extent computer science, physics, and agriculture), has raised various concerns. Most observers believe that the underlying problem is a paucity of American citizens willing to undertake graduate study in science and engineering. While some favor changing immigration policy to encourage foreign Ph.D.s to stay in the United States, others are calling for limits on Federal funding of foreign citizens in universities. In addition, some academics are concerned about the effect that the influx of foreigners is having on university teaching.

Related to the foreign component of the U.S. engineering work force are the effects of the defense buildup by the Reagan Administration. About one-quarter of all engineers now work on defense projects.[50] Some argue that these projects drain talent from the civilian sector, but others hold that military spending has boosted the supply of engineers. American students' loss of interest in engineering, particularly at the doctoral level, is a concern for the Department of Defense (DoD), since DoD's use of foreign engineers is largely prohibited by Federal security and employment laws. Partly to compensate, DoD is devising programs to bring more women and minorities into the talent pool.[51]

Photo credit: MESA Program

Large amounts of Federal R&D funds are spent on defense projects. Some argue that this spending draws disproportionately large numbers of students, particularly the most talented, away from the civilian sector and has detrimental effects on their training. Others argue that defense spending has boosted the supply of scientists and engineers, absorbed labor surpluses, and spurred leading-edge research. In either case, because of prohibitions on the use of foreign nationals in defense work, the Department of Defense is particularly keen to attract more U.S. citizens in the talent pool.

Engineering technicians and technologists form a large potential reserve stock of talent. The Nation's 1 million engineering technicians (compared with about 2.4 million engineers) are an important part of the engineering labor force, and they are a potential source of engineering skills. Some have already received training through specialized 2- and 4-year engineering technician and engineering technology programs, which are increasing nationally.[52]

The Need for Continuing, Life-Long Education

The fast pace of technological change has increased the need for mid-career retraining of engineers. Most agree that this need is not being met. Industry, which traditionally has preferred to hire and train young baccalaureate engineers rather than retrain its old stock, has not been a leader in continuing education.[53] Some universities, sensing the market opportunities, are reluctantly beginning to provide this training, but it is clear that their priorities remain teaching the young and conducting research. However, there are many engineers with out-of-date skills, and education to update them could be an efficient way to increase both the supply and quality of engineers.

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[50] National Research Council, *The Impact of Defense Spending on Nondefense Engineering Labor Markets* (Washington, DC: National Academy Press, 1986).

[51] For example, see Nina W. Kay, Huston-Tillotson College, Center for the Advancement of Science, Engineering, and Technology, "A Study to Determine and Test Factors Impacting on the Supply of Minority and Women Scientists, Engineers and Technologists for Defense Industries and Installations," unpublished manuscript, 1987.

[52] The problem is that engineering technology is still searching for an identity and full citizenship in the world of engineering. See Lawrence J. Wolf, "The Emerging Identity of Engineering Technology," *Engineering Education*, vol. 77, No. 7-8, April/May 1987, pp. 725-729. A bill, H.R. 2134, was introduced in the 100th Congress proposing a National Advanced Technicians Training Act. It calls for the National Science Foundation to designate 10 centers of excellence among community colleges to serve as clearinghouses and model training programs. See *Congressional Record*, vol. 133, No. 62, Apr. 22, 1987.

One promising approach to mid-career training is to use computer and information technology to provide training programs at workplaces, rather than at university campuses. The National Technological University, a consortium of 30 universities, offers master's-level engineering courses via satellite video, with two-way audio connections to companies' premises. Preliminary evaluation indicates that learning in this way is highly successful and that cost savings are substantial.[54] Other programs based on this model are beginning to be established, though widespread emulation is by no means assured.

Scope for Federal Policy in Engineering Education

Although industry and universities are the key players in engineering education, the Federal Government has a place and is increasing its policy influence. The international competitiveness of American industrial performance has caused the National Science Foundation (NSF) to pay a great deal more attention to engineering than it did a few years ago. Infrastructure, faculty, and students all need attention, and this intervention is timely. Some efforts to encourage the interplay of engineering theory with industry practice have been mounted in the NSF Engineering Research Centers, and additional steps could be taken by the national laboratories (such as playing host to cooperative education students). Evolving relationships between industry and universities will tend to narrow the gap between engineering as taught in engineering schools and as practiced in the world of employment.[55]

Federal R&D funding affects the supply of engineers indirectly, but substantially, by shaping industrial and academic engineering programs. Other than this influence, the Federal role in alleviating shortages of particular engineering specialties is limited to assisting undergraduate and graduate education, technician training, and continuing education. In the long run, interventions in the elementary and secondary education of students in mathematics and science, where talent is first identified and nurtured, will be necessary.[56]

Most engineering institutions will require not only Federal help in refurbishing their equipment and facilities, but assistance in inducing U.S. students to pursue graduate study. Most schools can neither acquire the costly design and production technology equipment that has swept through industry in the past decade, nor afford to turn away the impressive foreign talent clamoring for admission. Engineering institutions will have to juggle the resources at their disposal and adapt their pedagogical use of technology, both local and remote, to maintain the quality of education they offer.

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[53] There are notable exceptions, such as IBM and Hewlett-Packard. Estimates of the cost of retraining by U.S. industry—all personnel, not just engineers—range into the billions of dollars.

[54] A task force of the American Society for Engineering Education recently lauded the pioneering efforts of the Association for Media-Based Continuing Education for Engineers (a consortium founded in 1976 with funding from the National Science Foundation and the Sloan Foundation), as well as the National Technological University, for their "integration of learning modules with new communications technologies in order to free continuing education from time and distance constraints." American Society for Engineering Education, *A National Action Agenda for Engineering Education* (Washington, DC: 1987), p. 28.

[55] An example is the Semiconductor Research Corp. formed in 1982 to facilitate technology transfer among U.S. industry, government, and institutions of higher learning. See Ralph K. Cavin, III and D. Howard Phillips, "SRC: A Model of Industry-University Cooperation," *Engineering Education*, vol. 78, No. 4, January 1988, pp. 224-227.

[56] The National Action Council for Minorities in Engineering, the Southeastern Consortium for Minorities in Engineering, and the Junior Engineering Technology Society all sponsor programs dedicated to augmenting school experiences and creating interest in engineering as a career. See, for example, National Action Council for Minorities in Engineering, *Long Range Plan 1986-1995* (New York, NY: December 1986).

GRADUATE EDUCATION: ENTERING THE RESEARCH WORK FORCE

Key Questions

- How healthy is graduate education? How are research universities responding to the cooler climate for academic research and an increased emphasis on exploitable areas of science than prevailed two decades ago?
- How important is Federal funding of graduate education? Are some support mechanisms more effective than others in expediting completion of the Ph.D.?
- What factors seem to attract students, particularly women and minorities, to graduate study in science and eventual degree-taking?

Key Findings

- The quality of most Ph.D.-granting science programs and their graduates is very high. The university-based research apprenticeship is a strength of the U.S. system, and in many fields sets a global standard.
- Graduate education in the sciences is a long (an average of 7 to 8 years after the baccalaureate) and expensive process; a variety of support mechanisms (teaching assistantships, research assistantships, and fellowships) sustain students en route to receipt of the Ph.D.
- Federal funding has a direct positive effect on Ph.D. production. Fellowships and traineeships in particular have been a straightforward way to increase Ph.D. production in science and engineering.
- The size of the debt incurred during undergraduate education may deter minority students from electing graduate study.
- In retrospect, infusion of Federal R&D funds to science and engineering graduate programs in the 1960s was a principal cause of the rapid expansion of American graduate schools. As the number of scientists and engineers has grown, so has the competition for research grants and the need for equipment and faculty. This expansion has taxed the system of university basic research and graduate training, and decreased the attractiveness of academic careers.

Acculturation to the Research Environment

Beyond the baccalaureate degree, the educational system offers students two further goals: the master's and the doctoral degrees. For scientists, the doctorate is a research degree, and all hopes are set on it. Master's degrees in science are awarded as specialized stepping stones to doctorates; sometimes they facilitate field-switching, but often they are seen merely as consolation prizes.[57] Master's degrees normally involve some research, but the Ph.D. certifies the ability to do independent research.

For those who enter them, doctoral programs in science signify not only the final step of formal education, but also the initiation into research communities.[58] A nation concerned about the research base of scientists must be deeply concerned about what is happening at graduate schools, for that is where the research base is formed and renewed.

Photo credit: University of Chicago

Graduate education in science and engineering involves both advanced study in specialist fields and an acculturation to the practice of scientific research. Students work closely with faculty who become their mentors in what is, in effect, an apprenticeship to research.

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[57] Judith S. Glazer, *The Master's Degree: Tradition, Diversity, Innovation*, ASHE-ERIC Higher Education Report No. 6 (Washington, DC: Association for the Study of Higher Education, 1986).

[58] Alan L. Porter et al., "The Role of the Dissertation in Scientific Careers," *American Scientist*, vol. 70, September-October 1982, pp. 475-481.

Fortunately, American graduate schools are of very high quality. Not only vital to our national competitiveness and quality of life, they are increasingly international resources. In their number, independence, and diversity, and in their historic integration of education with research, they are unparalleled. These same qualities make it difficult to assess their general health and the quality of their outputs, though the increasing numbers of foreign students and faculty entering America's graduate schools are taken by many as a testimony to their strength.

The intertwining of education and research may be the source of this strength; the graduate student is not only a student and scientist in training, but an apprentice researcher as well. Universities are entrusted with the responsibility for most basic research in the United States. Graduate students, especially at the doctoral level, therefore receive important experience in research at the highest professional level.

The Nation's university research enterprise, however, is in transition. After extraordinary growth in the 1950s and 1960s, Federal research funding entered a period of slower growth and decline in the 1970s and 1980s.[59] Graduate enrollments have paralleled funding trends, reflecting also the decline in faculty employment opportunities. Universities have responded by engaging in novel funding and management arrangements with industry and government to maintain their financial and academic health.[60]

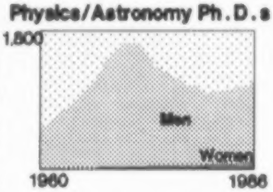
Ph.D. Awards—Toward a Steady State

An OTA analysis of the number of doctorates awarded in each field of science and engineering shows that, during the 1960s, doctorate production underwent a sustained rise that is correlated with increases in Federal funding of research and fellowships. As seen in figure 3-9, graduate enrollments more than doubled between 1958 and 1970, rising from 314,000 to 816,000 as Federal support grew. Since then, slower growth in Federal funding of both R&D and fellowships has been associated with essentially level production of Ph.D.s (figure 3-10).[61]

However, these degree patterns—as depicted by the figures below—have not been uniform. They vary substantially from field to field, and by sex. Also notable is the new role in American graduate programs of foreign citizens. The following are some broad trends:

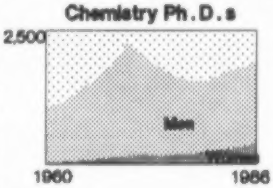
- Graduate physics enrollments are rising, but the increase is due solely to foreign citizens (who constitute one-third). Most physics Ph.D.s go on to postdoctoral appointments and stay in universities. Women earn only about 7 percent of physics doctorates; foreign nationals earn over three times as many.

Physics/Astronomy Ph.D.s



- There is an active industrial market for chemistry Ph.D.s, and chemists are relatively mobile (with as many as one-third of their number employed in other fields). About 25 percent of chemistry Ph.D.s are awarded to foreign nationals, and 20 percent to women.

Chemistry Ph.D.s



- Ph.D. production in earth and environmental sciences has been stable during the last decade, following a rapid rise in the 1960s, with geo-

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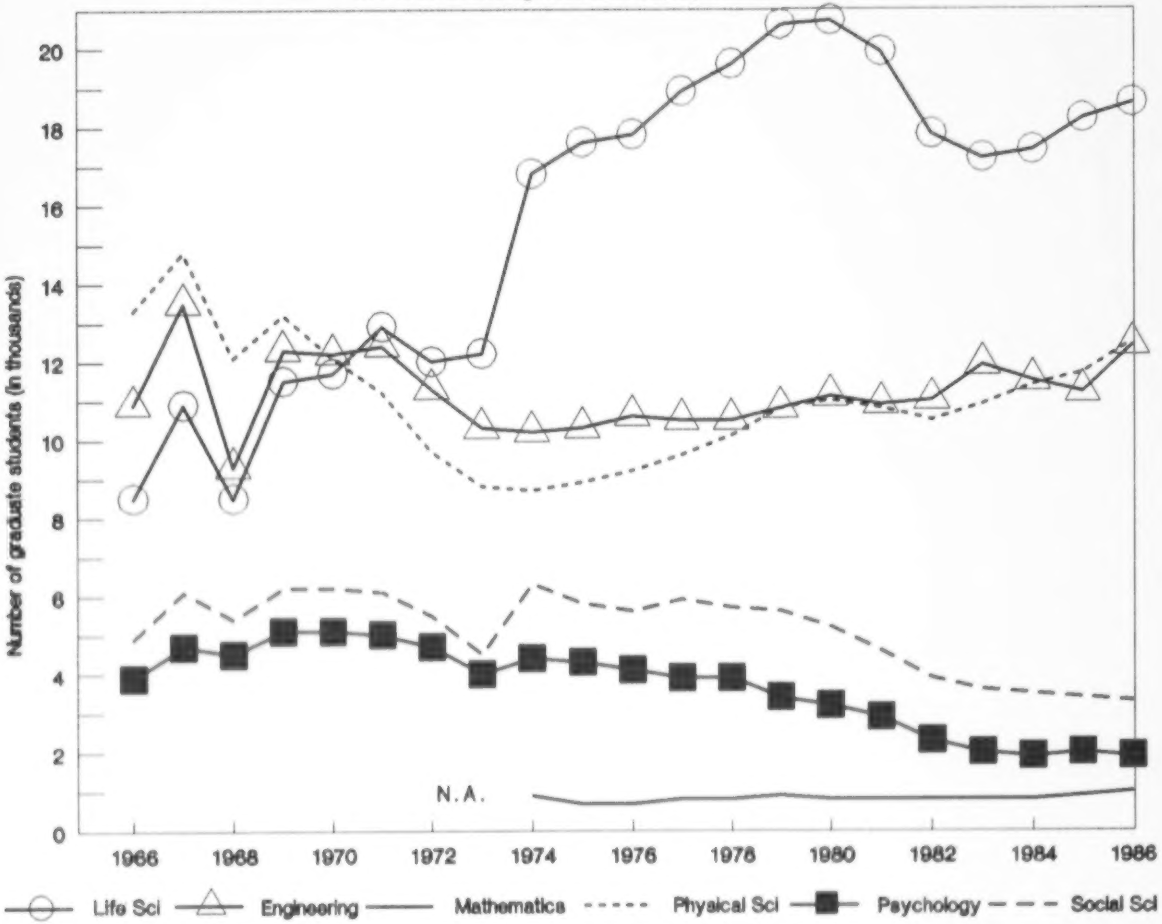
[59] Don I. Phillips and Benjamin S.P. Shen (eds.), *Research in the Age of the Steady-State University*, American Association for the Advancement of Science Selected Symposium 60 (Boulder, CO: Westview Press, 1982).

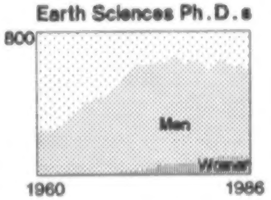
[60] For an overview, see White House Science Council, *Panel on the Health of U.S. Colleges and Universities* (Washington, DC: Office of Science and Technology Policy, 1986). The most celebrated contemporary cases of university accommodation to financial pressures concern partnerships with industry over biotechnology and with the Department of Defense over Strategic Defense Initiative research. See, for example, Dorothy Nelkin and Richard Nelson, "Commentary: University-Industry Alliances," *Science, Technology, & Human Values*, vol. 12, No. 1, winter 1987, pp. 65-74. Universities' most politicized responses to funding pressures have perhaps best been expressed in the competition over siting of the Superconducting Super Collider, and debate over peer review and the growth in congressional earmarking for building construction (laboratories, libraries, centers) on university campuses. For a congressional perspective, see Sherwood L. Boehlert, "Money, Science, and the SSC," *Chemical & Engineering News*, vol. 66, No. 1, Jan. 4, 1988, p. 5.

[61] These data and those discussed below are detailed in Office of Technology Assessment, op. cit., footnote 6.

Figure 3-9.—Full-Time Science/Engineering Graduate Students With Federal Support in Ph.D.-Granting Institutions, by Field, 1966-86



SOURCE: National Science Foundation, Science Resources Studies, *Academic Science/Engineering: Graduate Enrollment and Support.*



logical science supplying more than half the total. Recent enrollments are down. Women earn 20 percent of Ph.D.s awarded, and 20 percent go to foreign nationals.

- Most Ph.D. mathematicians are employed in universities. Ph.D. awards have dropped by more than half during the last 15 years, and about one-third go to foreign nationals (who, with naturalized citizens and foreign permanent residents, form about 15 percent of the Ph.D. mathematics work force). Forty percent of mathematics baccalaureates are awarded to women, but only 15 percent of the Ph.D.s.

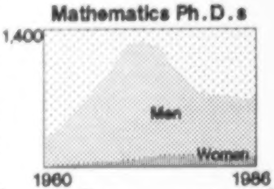
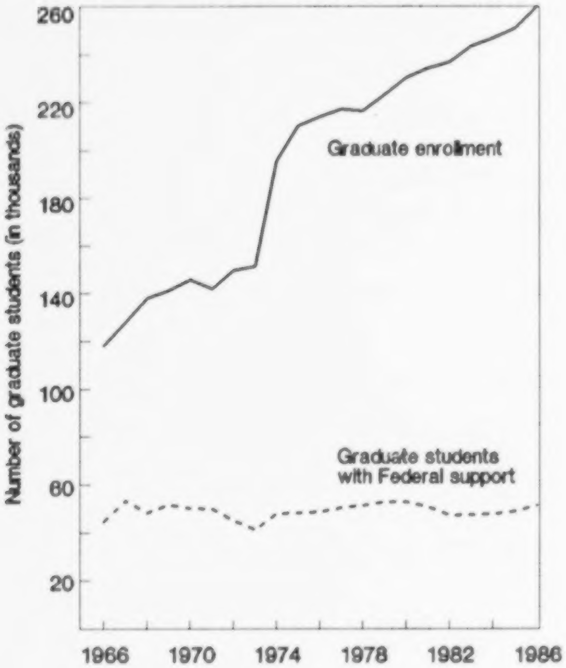
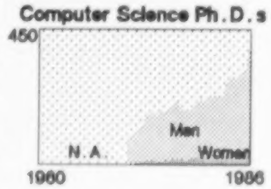


Figure 3-10.—Full-Time Science/Engineering Graduate Students With Federal Support in Ph.D.-Granting Institutions, 1966-86

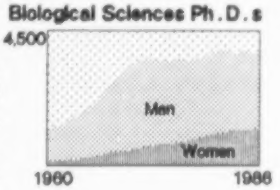


SOURCE: National Science Foundation, Science Resources Studies, *Academic Science/Engineering: Graduate Enrollment and Support.*

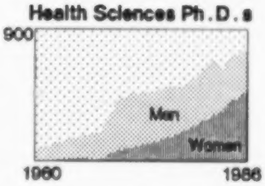
- Computer science has been the fastest growing field of science at all degree levels. Competition for computer science Ph.D.s is keen. Foreign citizens receive one-third of the doctorates (and form one-third of computer science faculties). Women earn 10 percent of the doctorates.



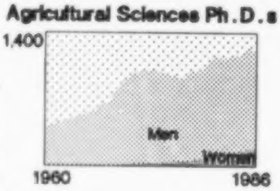
- There is a strong industrial market for doctorates in the biological sciences. Ph.D. production has been stable for the last 10 years, after a decade of increases. Women earn one-third of the Ph.D.s awarded.



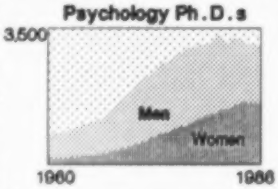
- The number of Ph.D.s awarded in health and medical sciences has increased by 50 percent in the last decade. Most are earned by women; foreign citizens account for about 13 percent.



- Ph.D.s in agricultural sciences have been growing slightly in the last 15 years. Foreign citizens have received about one-third of the Ph.D.s awarded since 1975, but the vast majority return to their native countries.



- Numbers of Ph.D.s in psychology have grown in the last decade, as the numbers of doctorates awarded in other social and behavioral science fields have declined. Enrollments in psychology Ph.D. programs, however, now favor clinical specialties over research and experimental specialties. Women earn more than half of Ph.D.s.



Attrition in graduate school represents a loss of talent to the research work force. As many as half of those who enroll in doctoral programs in science and engineering fail to graduate. Despite the rigorous selection of these students by schools, undergraduate programs, the results of Graduate Record Examinations (GRE), and the availability of financial resources, they are still vulnerable. Reducing their vulnerability would be an easy way to increase the size of the research work force. Increasing the number of fellowships awarded, for example, is a proven method of increasing retention (discussed below). There are large field variations, however, and, since it takes science students an average of 7 to 8 years to receive these degrees, some attrition is inevitable. There is no consensus on what the "natural" rate of attrition should be and how Ph.D.

Photo credit: Daniel S. Brody, University of Wisconsin, and The Chronicle of Higher Education

Attrition of graduate students, already a carefully selected and able group, is a serious loss of talent to the research work force; only about half of those who enroll as graduate students in science and engineering eventually graduate with doctorates. Females are especially likely to leave graduate school before graduation. For many students, graduate study is low-paying, lonely, and all-encompassing labor; and few universities have retention programs to help students through these years.

dropouts in particular reflect on the quality of the existing research work force.[62]

The Research Universities

The major research universities educate the majority of the Nation's science and engineering Ph.D.s. These universities number about 100 (out of 330 universities granting Ph.D.s in science). These 100 also win the lion's share of Federal R&D funds; collectively they receive 82 percent of Federal academic science and engineering funds and enroll three-quarters of the full-time graduate students.[63]

Except for a cluster of midwestern (mainly public) institutions, most of the research universities are privately controlled and concentrated on the Atlantic and Pacific coasts. Although their competitive advantage derives from the quality of their basic research, they are often enlisted in Federal research programs aimed at solving social, military, or market problems (such as energy programs in the 1970s), and in industry-funded applied research programs in, for example, materials and microelectronics.

In the 1980s, a changing balance between the competing forces that influence and fund the research universities has challenged graduate education. Despite the Federal Government's vigorous commitment to maintaining basic research funding, the amount of Federal funds offered to the research universities has been declining in real terms, and an increasing fraction has been allocated to military projects.[64] Simultaneously, links with industry have flourished and signs of a reorientation toward applied research are apparent. That reorientation has been encouraged by some States, which have seized on science and technology as drivers of their local economies and devised programs to involve institutions of higher education directly in economic development.[65] Figure 3-11 shows the sources of funding on which U.S. universities and colleges depend. At the same time, many university administrators are finding that science and engineering are victims of their own success; their accomplishments foster the need for ever more costly scientific equipment essential for continued exploration of the natural and human worlds.

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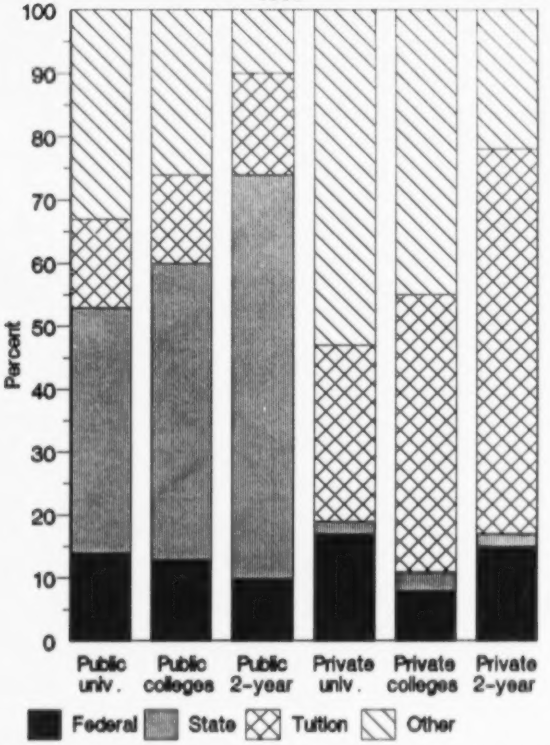
[62] Attrition is not a popular topic for study, but see Penelope Jacks et al., "The ABCs of ABDs: A Study of Incomplete Doctorates," *Improving College and University Teaching*, vol. 31, No. 2, spring 1983, pp. 74-81; Ellen M. Benkin, University of California at Los Angeles, "Where Have All the Doctoral Students Gone? A Study of Doctoral Student Attrition at UCLA," unpublished doctoral dissertation, 1984.

[63] U.S. General Accounting Office, *University Research Funding: Patterns of Distribution of Federal Research Funds to Universities*, RCED-87-67BR (Washington, DC: U.S. Government Printing Office, February 1987).

[64] National Science Board, op. cit., footnote 4, ch. 2; Susan L. Sauer (ed.), *R&D in FY 1988: R&D Policies, Budgets, and Economic Competitiveness* (Washington, DC: American Association for the Advancement of Science, 1987), pp. 11-27.

[65] State and regional commissions on science and technology, championed in the late 1970s and early 1980s by North Carolina and New Jersey, are becoming visible resource brokers. Outcomes of these university-industry-government partnerships—jobs, technology transfer, and incentives for further cooperation—remain to be assessed.

Figure 3-11.—Higher Education Revenue Sources, 1986



SOURCE: U.S. Department of Education, Center for Education Statistics, "Financial Statistics of Institutions of Higher Education," and unpublished data.

Graduate Education in Transition

Students enroll in graduate programs in science for many reasons; foremost among them is interest in research careers. The attractiveness of a research career is strongly influenced by the health of the research universities' research enterprise. That health is not as robust as it could be. Fortified during the 1950s and 1960s by an increasingly rich diet of Federal funds, university research now makes do with a sparser diet of more focused Federal funding. The university basic research and graduate training system can be characterized as in transition to a "steady state" of Federal funding, offset in part by increased industrial funding. For nearly two decades, the research enterprise has been adjusting in this way to a smaller Federal role in R&D support.[66]

Symptoms of this transition are readily apparent. The professoriate is aging. Competition for Federal research funds causes an overemphasis on proposal writing and a dearth of proposal awards, constrained career opportunities for those not on the tenure track, and a consequent growing cadre of soft-monied "academic marginals" and permanent postdoctoral appointees.[67] Still, there is a growing shortage of faculty in some science fields. Retirements are expected to rise; one-third of the professoriate will be replaced in the next 15 years.[68] The current tenure glut that has forced universities to create non-tenure-track positions may be relieved somewhat by these retirements.[69] But universities may not again allow the ranks of permanent faculty to swell, as they did in the golden era of the 1960s, by filling vacated positions with new full-time tenured and tenurable faculty. A dual career ladder may develop in which the traditional professoriate, combining scholarship and teaching, is augmented by new positions giving the academic work force elasticity in response to shifts in Federal and industrial research priorities.[70]

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[66] David A. Hamburg, Carnegie Foundation, testimony before the U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, July 9, 1985, pp. 29-30. A fuller discussion is contained in Phillips and Shen, op. cit., footnote 59, and U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering—A Technical Memorandum*, forthcoming, summer 1988. For a similar perspective on British science, see John Ziman, *Science in a "Steady State": The Research System in Transition* (London: Science Policy Support Group, December 1987).

[67] Analysis of this transition is based in part on Edward J. Hackett, "Science in the Steady State: The Changing Research University," OTA contractor report, September 1987. Also see Harvey Brooks, "What Is the National Agenda for Science, and How Did It Come About?" *American Scientist*, vol. 75, No. 5, September-October 1987, pp. 511-517.

[68] Irving R. Buchen, "Faculty for the Future: Universities Have a Rare Opportunity," *The Futurist*, vol. 21, No. 6, November-December 1987, p. 22; H.R. Bowen and J.H. Shuster, *American Professors: A National Resource Imperiled* (New York, NY: Oxford University Press, 1986).

[69] The elimination in 1994 of the Federal mandatory retirement age of 70, however, is unlikely to create a glut of "graying" professors. The age distribution of faculty varies by discipline (computer science faculty are comparatively young, physics faculty old) and spotty data cloud the national picture. Historically, faculty retirements have not been influenced by the mandatory retirement age. Inducements to early retirement, especially benefits offered, are more effective. So planning at the institutional level (and by professional societies—the American Institute of Physics has been studying the issue for over a year) is essential to foresee possible shortages. See Carolyn J. Mooney, "Expected End of Mandatory Retirement in 1990s Unlikely to Cause Glut of Professors, Study Finds," *The Chronicle of Higher Education*, vol. 34, No. 16, Dec. 16, 1987, pp. A1, 11; Samuel E. Kellams and Jay L. Chronister, "Life After Early Retirement: Faculty Activities and Perceptions," Center for the Study of Higher Education, University of Virginia, January 1988.

The increasing emphasis on industrial and applied research is also apparent in the rise of research centers, as a complement to project-based funding, and emphasis on team and interdisciplinary research. New pressures for accountability in scientific research are increasing the paperwork burden on the applicants for and recipients of individual investigator awards in universities, without necessarily leading to any measurably better outcomes.[71] **OTA concludes that the attractiveness of an academic research career is considerably reduced from its peak of two decades ago, due largely to the adjustment to steady-state conditions. The character of the university research enterprise is changing, with basic research and scholarship giving way in part to more industrially focused research and a more directed Federal role.**[72]

Whether as a cause or consequence of academia's diminished attractiveness, increasing numbers of new Ph.D.s in science are entering industry. This change in the market for Ph.D.s is reflected in the content and orientation of students' graduate school experiences, which are becoming more industry-oriented in some fields.[73]

The proportion of U.S. citizens with natural science baccalaureates who earn Ph.D.s—never very large—has declined in recent years. The ratio of U.S. Ph.D.s produced in 1975 to baccalaureates produced in 1965 was 1 to 10; it is anticipated that about 5 percent of the recipients of baccalaureate degrees in science in 1984 will ultimately earn a science or engineering Ph.D.[74] Popular explanations for American citizens not pursuing doctoral studies are the time it takes to earn the doctorate, the reduction in stipend support and its replacement with less attractive loans, and a poor labor market for Ph.D.s, particularly in universities.[75] There is little immediate prospect for change in these conditions. If these conditions do not change, enrollments of foreign citizens are likely to increase (if graduate schools maintain their current size and range of research programs).

Foreign citizens are increasingly important to American graduate schools. They are indispensable in some fields of science, as both students and faculty. They fill graduate student places that U.S. citizens are reluctant to fill, they teach undergraduates as teaching assistants, and they keep university research alive as research assistants. While foreign students are required by the Immigration and Naturalization Service to demonstrate that they will be funded for at least 1 year of study, once enrolled in graduate schools they can seek and be awarded many fellowships and assistantships in the same way as citizens. Thus, a significant proportion of Federal funds for science and engineering research at universities is used to educate foreign along with U.S. citizens. Some argue that this funding should be halted, but most believe that the United States gains in the long run from this flow of talent into the country.[76] Many of these students stay, acquire permanent visas, and contribute to the scientific vitality of the Nation. The rest return home with skills, knowledge, and increased cultural awareness. Providing graduate education to foreign students is becoming a major export activity of the United States, with tuition and board payments from abroad estimated by some at $2 billion annually in all disciplines, about the size of the NSF budget.

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[70] These "academic marginals" are typically appointed to "unfaculty" posts affiliated with research centers and institutes on campus. This is elaborated in Office of Technology Assessment, op. cit., footnote 66, but see Albert H. Teich, "Research Centers and Non-Faculty Researchers: A New Academic Role," in Phillips and Shen (eds.), op. cit., footnote 59, pp. 91-108.

[71] For example, see Deborah Shapley and Rustum Roy, *Lost at the Frontier: U.S. Science and Technology Policy Adrift* (Philadelphia, PA: ISI Press, 1985), chs. 4 and 6.

[72] "In the 1980s, Congress has repeatedly signaled its support for restructuring the research system and breaking down the old barriers. The National Cooperative Research and Development Act of 1984 was designed to facilitate joint research among firms in an industry, by offering certain immunities to antitrust actions against such efforts under appropriate conditions. Congress has enthusiastically supported the National Science Foundation's Engineering Research Centers, Industry/University Cooperative Research Centers, and Presidential Young Investigator programs, each of which is intended to stimulate cooperative research between universities and industry. Similarly, the Stevenson-Wydler Technology Innovation Act of 1980, and its amendments, the Federal Technology Transfer Act of 1986—along with several recent changes to the patent law—have been designed to stimulate cooperative industrial research . . . ." Christopher T. Hill, "A New Era for Strategic Alliances: A Congressional Perspective," *Engineering Education*, vol. 78, No. 4, January 1988, pp. 220-221.

[73] Michael J. Gluck, "Industrial Support of University Training and Research: Implications for Scientific Training in the 'Steady State'," OTA contractor report, August 1987; also see David Blumenthal et al., "Industry Support of University Research in Biotechnology: An Industry Perspective," *Science*, vol. 231, June 13, 1986, pp. 1361-1366.

[74] National Science Foundation, *The Science and Engineering Pipeline*, PRA Report 87-2 (Washington, DC: April 1987), p. 4.

[75] At least one commentator attributes the indifference of U.S. undergraduate students in science and engineering to undertake graduate study to being "uninformed and misinformed about this option." His solution, based on meetings with participants in a National Aeronautics and Space Administration summer internship program, is "communication between individual and faculty members and their students." See Francis J. Montegani, "Why U.S. Science and Engineering Students Pass Up Graduate School—A Different View," *Engineering Education*, vol. 78, No. 4, January 1988, p. 257.

[76] For a discussion of the economic benefits to U.S. society from foreign students, see Donald R. Winkler, "The Costs and Benefits of Foreign Students in United States Higher Education," *Journal of Public Policy*, vol. 4, No. 2, 1984, pp. 115-138.

Elinor G. Barber (ed.), *Foreign Student Flows*, Research Report No. 7 (New York, NY: Institute for International Education, 1985).

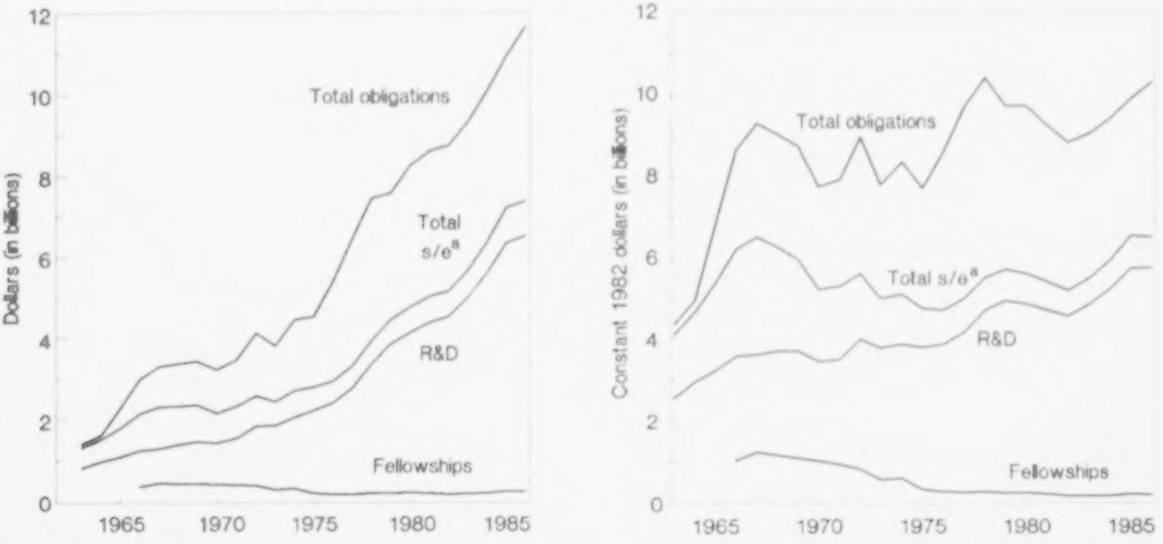
FUNDING OF STUDENTS AND INSTITUTIONS: A TOOL OF FEDERAL POLICY

The Federal Government has a variety of influences, both direct and indirect, on science and engineering education at the undergraduate and graduate levels. Among the direct influences, some, such as basic research spending in universities, are specific to science and engineering. Others, such as support of students and institutions through student loans, infrastructure grants, and other exercises of general Federal stewardship over education and research, have broader application (see figure 3-12).

Indirect influences include tax policies, which affect the nonprofit status of private institutions of higher education and the tax treatment of personal expenditures on education; the military draft and the G.I. bill; laws that prohibit discrimination, such as Title VI of the Civil Rights Act of 1964 and Title IX of the Education Amendments of 1972; and economic policies.

A vital source of indirect Federal influence is the mounting of R&D programs, which can boost the output of scientists and engineers by providing research jobs in government, industry, and academic institutions. (In academic institutions, they also provide student support in the form of research assistantships.) Programs that are large and sustained attract people into undergraduate and graduate studies in relevant fields, thus also creating demand for faculty. Often, such programs are accompanied

Figure 3-12.—Federal Obligations to Universities and Colleges by Type of Activity, 1963-86



[a]Academic science/engineering encompasses Federal support for academic R&D (about 90 percent of total), facilities and equipment, fellowships, and other general science/engineering activities. Total academic obligations include, in addition to academic science/engineering, direct Federal obligations for research, facilities, and institutional support not related to science/engineering. Total obligations do not include loans, student support, or other indirect Federal support.

SOURCE: National Science Foundation, Science Resources Studies, *Federal Support to Universities, Collegns, and Selected Nonprofit Institutions.*

Photo credit: National Institutes of Health

Major Federal R&D programs, such as the War on Cancer in the 1970s, have had the indirect effect of increasing the number of research scientists and engineers. These programs work in two ways: they fund research assistantships in graduate school and increase the attractiveness of scientific research as a career option.

by fellowships and other assistance intended to encourage students to enter relevant fields. The National Defense Education Act of 1958 (spurred by Sputnik), the Apollo Program of the 1960s, and the War on Cancer launched in 1971 provide ample evidence of the Federal power to mobilize research talent.

Federal influence varies greatly by field. In scientific fields that involve mainly academic or basic research, the career outlook for students depends heavily on Federal research programs that dominate universities' research agendas and those of many industries.

Thus, Federal R&D programs affect graduate science and engineering education in four major ways. First, by setting the national research agenda and establishing the demand for science and engineering, they influence students' choices of fields and careers in response to the job markets. Second, Federal funds for the infrastructure of research and education, including institutions, facilities, equipment, faculty, and technicians, maintain the environment for instruction. Third, Federal research grants and contracts support science and engineering graduate students (and a few undergraduates) with research assistantships. Finally, student fellowships and traineeships are awarded on the basis of merit directly to U.S. students by Federal agencies.

Federal programs for undergraduate and graduate education in science and engineering have been mounted by the U.S. Department of Education, NSF, and many other agencies. The scope of these programs and their variety is so vast that it is impossible to evaluate their independent effects or even their overall objectives. Two patterns can be discerned, however, in recent Federal policies: direct funding of individual students to improve access to undergraduate education, and merit-based support to attract graduate students in science and engineering.

Federal Influence on Undergraduate Education

Since science and engineering baccalaureates have maintained a remarkably constant share of total baccalaureates, it is reasonable to conclude that any Federal program that alters the size of undergraduate enrollments will have a corresponding impact on enrollments in science and engineering majors. This proportional pattern is conspicuous throughout the past 30 years, through enrollment boosts resulting from the G.I. bill and the growing participation of larger numbers of women and minority members. This is perhaps the clearest pattern visible in all of higher education. However, Ph.D. awards show no clear relation to B.S. awards in science and engineering; graduate enrollments respond instead to fellowship funding and em,loyment trends in research.

A detailed analysis of Federal influence on higher education reveals that the scale of R&D spend-

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An analysis of how universities responded to the need for more scientists and engineers to support the National Aeronautics and Space Administration and the aerospace industry during the Apollo era, and the effects of ensuing cutbacks in the 1970s, appears in Arnold S. Levine, "The Apollo Program: Science/Engineering Personnel Demand Created by a Federal Research Mission," OTA contractor report, December 1986. Also see W. Henry Lambright, *Launching NASA's Sustaining University Program*, Limited Advance Edition (Inter-University Case Program, Inc., 1969); Kenneth E. Studer and Daryl E. Chubin, *The Cancer Mission: Social Contexts of Biomedical Research* (Beverly Hills, CA: Sage Publications, 1980), esp. ch. 3.

Vetter and Hertzfeld, op. cit., footnote 1. Also see Lawrence E. Gladieux and Gwendolyn L. Lewis, *The Federal Government and Higher Education: Traditions, Trends, Stakes, and Issues* (Washington, DC: The Washington Office of the College Board, October 1987).

ing, of which the Federal Government contributes about half, has been a major determinant of the supply of scientists and engineers. OTA concludes that legislation increasing opportunity to pursue higher education has had important positive effects on the production of baccalaureate scientists and engineers.

Except for tax-based funds provided to State colleges and universities, the working assumption made in the American system of higher education is that students and their families should pay for it. Support is available to the economically disadvantaged from the Federal Government and from many educational institutions themselves. The Federal Government also provides student loans, which are important in helping retain students through undergraduate education.[80] For the nontraditional student—older, socially or economically disadvantaged, female, minority, or physically handicapped—loans can make the difference between access to higher degrees and blunted career aspirations, since the opportunity costs of higher education for these students are greater. Blacks are more sensitive to loan burdens than whites; they are also slightly more likely to drop out of the science and engineering talent pool under the influences of mounting debt and alternative job opportunities.[81] Kirschner and Thrift note:

> Often, students must assume debt larger than their families' annual income to pay college expenses. Understandably, some students see debt as an unacceptable risk, limiting their options for education.[82]

Support for undergraduate science students differs little from support for undergraduate students as a whole. Students are more likely to stay in school if they receive substantial grants or scholarships. Those who receive grants totaling more than half of tuition are less likely to drop out than those who receive no grants, Pell grants, or some grants.[83] Loans are growing in importance as a proportion of undergraduate student support. Federally supported loan programs grew dramatically through the 1970s and early 1980s, twice as rapidly as overall Federal student aid.[84]

The National Science Foundation has long been a small source of support for undergraduate science and engineering students. Through the 1960s and early 1970s, NSF spent about $30 million per year ($100 million in 1985 dollars) on undergraduate science education. Funding peaked in 1965 and declined until very recently.[85]

NSF support has been concentrated in 4-year colleges without extensive Federal funding or research facilities, where it is intended to provide undergraduate research opportunities. NSF has always preferred funding a few good students, rather than the mass of science and engineering undergraduates.[86] NSF could expand its focus on undergraduate science education through its new Office of Undergraduate Science, Engineering, and Mathematics Education in the Science and Engineering Education Directorate. This office coordinates curriculum development, faculty training, and instructional equipment efforts.[57]

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[80] Arthur M. Hauptman and Charles J. Andersen, "Background Paper on American Higher Education: Report to the Commission on National Challenges in Higher Education," Dec. 16, 1987, p. 3.

[81] Julia Heath and Howard P. Tuckman, "The Effects of Tuition Level and Financial Aid on the Demand for the Advanced Terminal Degree," *Economics of Education Review*, vol. 6, No. 3, summer 1987, pp. 227-238. Michael T. Nettles, *Financial Aid and Minority Participation in Graduate Education*, Research Report of the Minority Graduate Education Project (Washington, DC: Graduate Record Examinations Board and Educational Testing Service, 1987), pp. 3-5.

[82] Alan H. Kirschner and Julianne Still Thrift, *Access to College: The Impact of Federal Financial Aid Policies at Private Historically Black Colleges* (Washington, DC: United Negro College Fund and National Institute of Independent Colleges and Universities, 1987), p. 29.

[83] Undergraduate science students have about the same average student loan load as other undergraduates. Engineering students carry slightly higher debt loads, probably in anticipation of higher earnings. Science and engineering students tend to receive slightly more campus-based aid than average, owing to their higher than average academic ability rather than to their choice of majors. Applied Systems Inc., op. cit., footnote 20. Also see *Manpower Comments*, June 1987, p. 30.

[84] The College Board, *Trends in Student Aid: 1980 to 1987* (Washington, DC: The Washington Office of the College Board, November 1987). Taken together, all forms of Federal financial aid cover about half the costs incurred by students in private colleges and over 60 percent of the costs for students attending private historically Black colleges. Kirschner and Thrift, op. cit., footnote 82, p. 22.

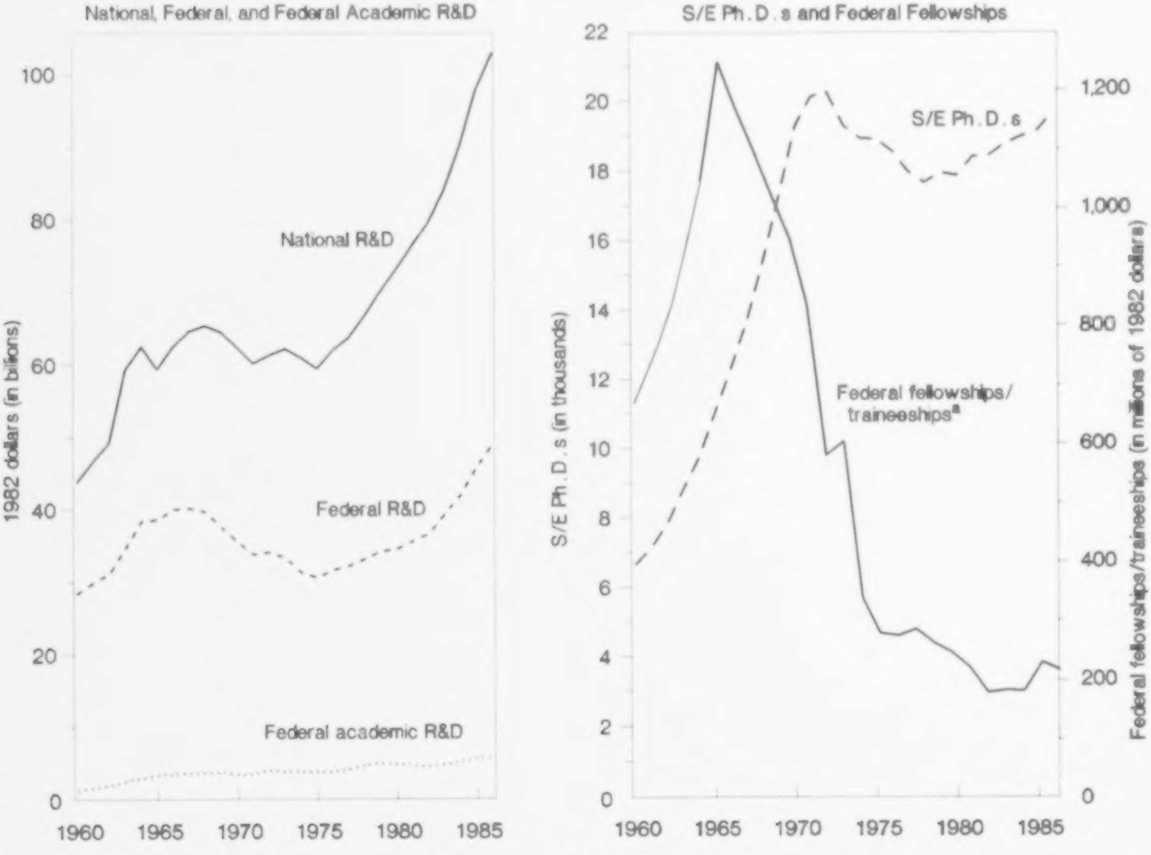
[85] Laurie Garduque, "A Look at NSF's Educational Research Budget," *Educational Researcher*, June-July 1987, pp. 18-19, 23.

[86] National Science Board, Task Committee on Undergraduate Science and Engineering Education, NSB-86-100, *Undergraduate Science, Mathematics and Engineering Education* (Washington, DC: National Science Foundation, 1986), known as the Neal Report. This report identified three areas of undergraduate science and engineering education needing particular attention: equipping laboratories and making laboratory instruction an important and vibrant part of undergraduate education; upgrading the qualifications of faculty; and improving courses and curricula. The National Science Board estimated that of the $42 million spent on undergraduate education in the United States, about half goes to science and engineering. The Task Committee recommended that the National Science Foundation spend an additional $100 million each year on laboratory instruction, faculty enhancement, curriculum development, research participation, instructional equipment, and minority institutions. These funds could be highly leveraged through matching requirements as well as by 'setting examples' for universities, States, and industry to follow. The Task Committee also recommended that National Science Foundation, mission agency, and other research sponsors find new ways to involve undergraduates and undergraduate faculty in research.

Support of Doctoral Students: "Buying" Ph.D.s

Federal policy at the undergraduate level has historically been concerned mainly with ensuring access to educational opportunity. At the graduate level, Federal policy focuses on promoting professional training of a small pool of talented students who will form the core of the future research work force. Historical data show that doctoral level science and engineering benefit from the Government's general support for higher education and R&D (see

Figure 3-13.—National and Federal R&D Spending, Science/Engineering Ph.D.s, and Federal Fellowships, 1960-86 (constant 1982 dollars)



[a] Federal fellowships/traineeships from 1960 to 1964 are OTA estimates, based on Federal fellowship and traineeship data from Federal Interagency Committee on Education, *Report on Federal Predoctoral Student Support, Part 1*, 1970, cited in Robert G. Snyder, OTA contractor report, June 10, 1985, p. 49.

SOURCE: Data on R&D and fellowships from National Science Foundation, Science Resources Studies, *Academic Science/Engineering* and *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions*. Ph.D. data from Betty M. Vetter and Henry Hertzfeld, OTA contractor report, 1987, based on data from U.S. Department of Education, Center for Education Statistics.

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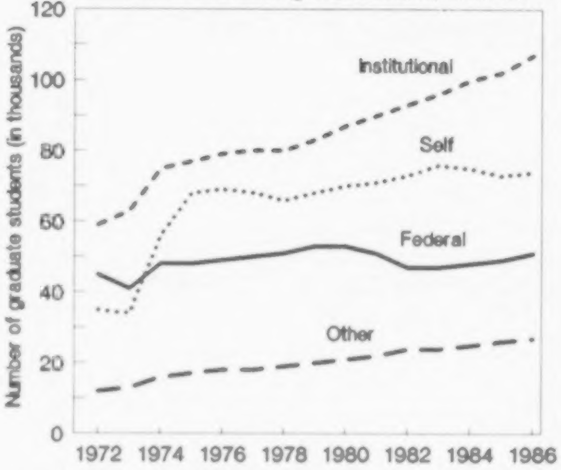
[57] Homer A. Neal, State University of New York, Stony Brook, testimony before U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Science, Research, and Technology, Feb. 19, 1987, pp. 20-41.

figure 3-13).[88] In each discipline, the attractiveness of a doctoral program in science and engineering has been strongly influenced both by the availability of fellowship and assistantship funding and by the overall outlook for research funding, which shapes the attractiveness of a career in research. OTA also found that the size of the debt incurred during undergraduate education does not affect majority students' graduate study decisions, but may act as a deterrent for prospective minority students.[89]

Up to the graduate level, Federal support of students and universities has diffuse impacts, since most is awarded without regard to academic field. Federal support of science and engineering graduate students, however, has increased since World War II, with periods of rapid expansion, slow growth, and decline.[90] Between World War II and the Sputnik-Apollo era, the Federal Government played a minor role in direct support of graduate students; in 1954, only 10 percent of science and engineering graduate students received Federal assistance. After passage of the National Defense Education Act, Federal support boomed. It peaked in 1967 when 42 percent of these students received some form of direct Federal assistance (49 percent in the natural sciences, 32 percent in the social sciences, and 45 percent in engineering). Through the late 1970s into the 1980s, the number of students federally supported declined, while support from other sources grew (see figure 3-14). In 1985, the Federal Government was the major source of support for 20 percent of full-time science and engineering students (26 percent in the natural sciences, 8 percent in the social sciences, and 20 percent in engineering).[91]

Figure 3-14.—Major Sources of Support, Science/Engineering Graduate Students in Ph.D.-Granting Institutions, 1972-86



SOURCE: National Science Foundation, Science Resources Studies, *Academic Science/Engineering: Graduate Enrollment and Support.*

The pattern of Federal support continues to shift, with the number of fellowships and traineeships declining and research assistantships (RAs) and loans growing in importance. The system is bolstered strongly by institutional support and State funding, mostly funneled through public institutions. Institutions and States support about 41 percent of graduate students, largely through teaching assistantships (TAs). Self-support has grown since the early 1970s; in 1985 about 30 percent of full-time students relied solely on their own funds. The attractiveness of doctoral studies varies with perceptions of affordability and of available support; once in graduate school, women and minorities are more likely to be self-supported.[92]

Federal fellowships are awarded to the "best" students, as defined by undergraduate accomplishments and GRE test scores, regardless of the institutions they attend. However, these students (about 16 percent of all graduate students) concentrate in the major research universities. Fellowship recipients earn their degrees faster and are more likely to join the science and engineering work force than those without such support.[93] Women fare worse than men or foreign students on temporary visas when it comes to obtaining fellowships; this pattern is believed to be an important factor in the attrition of women in graduate school.[94] **Federal fellowships, awarded to those identified as prepared for and committed to research careers, have been an effective way of "buying" new Ph.D.s.**

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[88] Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need to Know* (Washington, DC: Association of American Universities, 1986).

[89] Janet S. Hansen, *Student Loans: Are They Overburdening A Generation?* (Washington, DC: The Washington Office of The College Board, December 1986).

[90] Vetter and Hertzfeld, op. cit., footnote 3.

[91] Over one-third of science and engineering graduate students attend part time. They are more likely to be pursuing a master's degree and far less likely to receive Federal aid (except loans). See National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1985* (Washington, DC: 1987). Data refer to full-time graduate students in doctorate-granting institutions. Federal support is concentrated in this core population.

[92] Hansen, op. cit., footnote 89. Women, for example, are more likely than men to support themselves as graduate students. This is due only in part to women's choice of fields, such as social sciences, where less external support is available.

Federal research assistantships are tied to faculty grants. RAs support more than 20 percent of graduate students, providing valuable apprenticeship experiences. Recent Federal policy has shifted away from fellowships toward RAs. This shift may have inadvertently increased the accessibility of graduate study to foreign students, who are generally barred from receiving Federal fellowships. TAs (held by about 20 percent of graduate students) also support students in exchange for service to institutions. Almost half of graduate students are at least partly self-supporting, generally with loans.

In sum, a variety of Federal programs, not all intended to serve educational purposes, affect the graduate environment, and thus indirectly affect the supply and demand of scientists and engineers. Immigration laws, R&D tax credits, defense procurement, the taxing of student stipends, legislation to upgrade campus research facilities, and programs of curriculum, faculty, and center development, among other factors, can all affect the quantity and quality of the future science and engineering work force.

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[93] National Academy of Sciences, Committee on a Study for National Needs of Biomedical and Behavioral Research Personnel, *Personnel Needs and Training for Biomedical and Behavioral Research* (Washington, DC: 1981), pp. 7-10, 74-76. Prestigious postgraduate and faculty fellowships, such as the National Science Foundation's Presidential Young Investigator awards, continue this tradition of supporting, on a competitive and matching-fund basis, the very best talent.

[94] Vetter and Hertzfeld, op. cit., footnote 3.

Chapter 4

Policy Issues and Options

Photo credit: William Mills, Montgomery County Public Schools

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Chapter 4
Policy Issues and Options

INTRODUCTION

American schools, colleges, and universities have the capacity to provide enough scientists and engineers to meet the Nation's needs. Students and institutions can meet changing market needs, as evidenced by the response of engineering enrollments to the semiconductor industry boom in the late 1970s. However, many researchers, employers, and policymakers are concerned that future supply will be inadequate. In the early 1990s, the Nation will experience a decline in the number of college-age students (although some increase can be expected before the turn of the century). More important, fewer students, particularly those white males who have been the mainstay of science and engineering, seem to be interested in science and engineering careers. Women's interest in science and engineering, after rising for a long time, seems to have plateaued. Non-Asian minorities, traditionally poorly represented in science and engineering, will form a steadily increasing proportion of America's schoolchildren.

Two major trends are challenging the traditional educational route to a science or engineering career. First, the rising importance of minorities in the population will lead educators and employers to reach out to more diverse populations. Second, the end of expansion and the subsequent transition to a steady state of enrollments and research funding will require universities, employers, and the Federal Government to adjust their models and mechanisms of science and engineering recruitment.

Despite these trends, shortages of scientists and engineers are not inevitable. Generally, the labor market adjusts, albeit with transitory and sometimes costly shortages and surpluses. Rather than trying to direct market responses, policymakers should seek to prepare a cadre of versatile scientists and engineers for research and teaching careers, invest in an educational system that creates a reservoir of flexible talent for the work force, and ensure opportunities for the participation of all groups in science and engineering.

The Policy Setting: Federal Roles

The Federal Government has historically had both direct and indirect effects on the education of scientists and engineers (see table 4-1), but it is only one of many actors in the system. The Federal role in science and engineering education is most significant at the graduate level, more diffuse at the undergraduate level, and small in elementary and secondary education.

Federal investment in science education and training is undertaken for many reasons; there is no single objective or mission. One class of investments is in direct support of graduate students and production capacity at blue-chip universities. Other investments are made in newer, developing colleges and universities with growth potential, and in undergraduate and precollege education. Due to the uncertainty of payoffs from investing in creativity and reasons of efficiency and equality of access and geographical balance, Federal support is spread across different types of institutions and students.[1] Both short- and long-term investments are necessary in a marketplace where demographics, economics, and technology constantly change the criteria for success in education for the work force.

The educational process from grade school to graduate school is 20 years long. This means there are many possible Federal options for renewing the future supply of scientists and engineers. It is difficult, however, to distinguish which option would have the greatest impact. At each level of the educational system, there are many choices for action. Few measures guarantee predictable effects in the relatively short term; most are more speculative and longer term possibilities. Just as there are no immi-

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[1] The Federal Government can provide money, leverage power, and assist information and technology transfer. As a major investor in science and engineering education at all levels, it has more than local interests at heart and can be a catalyst.

Table 4-1.—Landmark Federal Legislation Affecting Science and Engineering Education

1862	**Morrill Act.** Established land grant colleges, and the precedent for Federal support of institutions of higher education.
1890	**Second Morrill Act.** Required States with dual systems of higher education to provide land grant institutions for Blacks as well as whites. Sixteen Black institutions were established as 1890 Land Grant colleges.
1937	**National Cancer Institute Act.** One of the first in a long line of health manpower/National Institutes of Health acts.
1944	**Serviceman's Readjustment Act (G.I. Bill).** Provided extensive Federal support for large numbers of new undergraduate and graduate students. Not targeted to science and engineering, but by increasing the number of college students increased the output of scientists and engineers. Nearly 8 million World War II veterans enrolled; many chose science and engineering majors.
1950	**National Science Foundation Act.** Established the National Science Foundation and included support of science education in the National Science Foundation's mission of supporting basic science. Set the tone for graduate science and engineering education: merit and geographical balance are the primary award criteria, with oversight of professional replenishment vested in the scientific community.
1951	**Selective Service Amendments of 1951.** Created draft deferrals for college students and for scientists. Following 1967, Act made students more vulnerable to the draft, and full-time graduate enrollment dropped as male students took deferrable full-time jobs.
1958	**National Defense Education Act.** Science and mathematics were major areas targeted for improvement through generous funding for equipment, guidance, testing, teacher training, and educational research. Increased the role of the Office of Education in science and engineering education. Authorized many graduate fellowships and undergraduate loans. The National Defense Education Act was expanded to most fields in 1964.
1964	**Civil Rights Act.** Title IV set up technical advice structure for elementary and secondary schools to desegregrate on the basis of sex, race, color, religion, or national origin. Title VII prohibited sex discrimination in employment (hiring, firing, pay, and working conditions).
1965	**Elementary and Secondary Education Act.** Established massive Federal support for schools and materials, particularly for schools with nontraditional and disadvantaged students. No focus on particular curricular area. Directed Federal education policy and money to special underserved populations (low-income, handicapped).
1965	**Higher Education Act.** First major Federal legislation for higher education not linked to a specific goal (e.g., national defense), but rather to promote equality of access, student freedom of choice, quality of education, and efficient use of human resources. Brought Federal money into higher education and expanded college enrollments. Supported continuing and cooperative education, libraries, teacher training, facilities, and student financial aid. Title II included a provision to support minority institutions.
1967-8	**Elementary and Secondary Education Amendments.** Authorized support of regional centers for education of handicapped, particularly deaf and blind. Supported bilingual education programs.
1972	**Education Amendments.** Consolidated higher education legislation prohibited sex discrimination in federally assisted education programs. Title IX prohibited sex bias in admission to vocational, professional, graduate, and public undergraduate institutions.
1974	**National Research Service Awards Act (National Institutes of Health).** Shifted emphasis of the National Institutes of Health training from growth to renewal and quality in a constrained budget. Set out the principle of requiring students to return services in exchange for support (not enforced). Instituted manpower planning. Fellowships by law must constitute 15 percent of the research training budget.
1980	**Science and Technology Equal Opportunities Act.** Promoted the full development and use of the scientific talent and technical skills of men and women of all ethnic, racial, and economic backgrounds. Directed a biennial report to assess opportunities and participation rates.
1984	**Education for Economic Security Act.** Targeted mathematics, science, computer learning, and foreign languages. Under this Act, the Department of Education provides modest funding, mostly on a formula basis, for: teacher training, magnet schools (designed for desegregation, but some with science and mathematics emphasis), and for improving mathematics and science education.
1986	**National Science, Engineering, and Mathematics Authorization Act of 1986.** Established a Task Force on Women, Minorities, and the Handicapped in Science and Technology in the Federal Government and in federally assisted research programs.

SOURCE: Office of Technology Assessment, 1988.

nent crises in replenishing the science and engineering work force, there are no quick fixes.

The following discussion sets out policy areas for possible congressional action, presented under two strategies labeled "retention" and "recruitment," along with two Federal management issues (see table 4-2). Within each policy area, options are listed and described. The overarching policy issue is whether the Federal Government allows the market for scientists and engineers to take its course or intervenes more boldly.

Two Strategies

The two broad strategies of retention and recruitment complement each other, and would operate best in tandem. The retention strategy is designed

Table 4-2.—Federal Policy Options To Improve Science and Engineering Education

The following list summarizes the policy options discussed in this chapter, along with *rough estimates* of the current level of Federal spending in that area, as well as the number of students, teachers, or educational institutions affected. The estimates have been compiled from the reported budgets of major, separately budgeted Federal programs, as well as estimates of discretionary spending (usually small amounts in the mission agencies) based on contacts with agencies. Many departments and agency laboratories also run small outreach programs using employee volunteers and donating equipment; there is no way to estimate the value or impact of these programs. In most areas a great deal of money is also spent by private organizations and individuals.

Policy Option and Number of Students Affected	Estimated 1988 Federal Spending
Retention	
1. Support graduate training[a]	unknown 52,000 students (20% of all graduate students)
fellowships and traineeships	$250 million 13,400 students (5% of all graduate students)
postdoctorates	$300 million to $400 million 17,000 students (70% of all postdoctorates)
2. Academic R&D spending/mission agencies	$5.5 billion
graduate research assistantships[a]	$500 million 33,000 students (12% of all graduate students)
3. Flow and retention of foreign students	—
4. Institutional support[b]	unknown
research colleges	unknown
historically Black colleges and universities[c]	$630 million to $750 million
research universities	unknown
5. Hands-on research experience	
research apprenticeships	$10 million to $12 million 5,000-7,000 undergraduates
cooperative education	$15 million 175,000-200,000 students (2%)
6. Targeted support for undergraduate science and engineering students (Pell grants, etc.)	$4 billion to $5 billion 4 million college students
Recruitment	
1. Intervention programs	
science/engineering (all agencies)	8,000-25,000 students
4H (U.S. Department of Agriculture)	5 million students
2. Elementary and secondary teaching	$120 million to $180 million
preservice and inservice training	$110 million to $150 million 10,000-250,000 teachers[d]
encourage and reward teachers	$1.2 million 106 teachers
3. Informal education	$13 million to $20 million
TV, fairs, camps, demonstrations	unknown
S&T centers	$10 million, 150 science centers
4. Improve opportunities for women	unknown
enforce Title IX	unknown
special support and intervention	unknown
5. Improve opportunities for minorities	unknown
enforce civil rights legislation	unknown
special support and intervention	unknown
6. Elementary and secondary education	
reproduce magnet schools	$75 million[e]
science-intensive schools and experiments	—[f]
adjust course-taking	—
review tracking	—
revise testing	—

table continues

continued from p. 85

Management of Federal Science and Engineering Education

1. National Science Foundation as lead agency in science education	
SEE Directorate	$140 million
Research and related directorates	$217 million
2. Federal coordination and data collection	$40 to $80 million[g]

NOTES:

[a] National Science Foundation 1986 data. Includes fellowships, traineeships, research and teaching assistantships, and loans for full-time graduate students in doctorate-granting institutions. The number of students includes only those graduate students whose major source of support is the Federal Government; thus, the number here underestimates the total number of graduate students receiving Federal support, though it reflects the allotment for institutional allowances as well as student stipends. The vast majority of Federal support goes to full-time students.

[b] Only those funds directly related to science and engineering instruction, facilities, and capability. Includes general development funds and capital funds for major science and engineering-related equipment, facilities, and libraries. Includes general support for historically Black colleges and universities (HBCUs) and Black land grant institutions. Does not include R&D, student support, or support for Federally-Funded R&D Centers.

[c] Only about 20 percent of this is directly related to science and engineering, and most of that is current R&D support. Only about $35 million goes to science and engineering-related institutional support (facilities, institutional and departmental development, and general support). The rest is legislatively mandated general Federal support, mostly out of the Department of Education but also the National Institutes of Health and the Department of Agriculture, for the approximately 100 historically Black institutions. One institution, Howard University, receives nearly one-third of Federal support for HBCUs.

[d] Teacher training and enrichment programs are diverse. Some, like the National Science Foundation and mission-agency sponsored workshops, training institutes, and summer research experiences, invest significant time and money in each teacher, but reach only a few hundred teachers a year. Under Title II of the Education for Economic Security Act, the Department of Education distributes money by formula for teacher training, and thus in principle reaches nearly all of the 1.5 million public school teachers (and some private school teachers), but is so diluted by formula distribution that only a few dollars reach each school and teacher.

[e] Under current criteria, Federal funding for magnet schools is given to those school districts under court orders to desegregate. While it reaches only a small number of school districts (45-50), it reaches some very large ones (and thus a greater proportion of students) and many of those districts with continuing and significant racial imbalances in the delivery of education.

[f] Non-Federal spending is about $1 million to $8 million, 500-2,000 students.

[g] Includes National Science Foundation spending on data collection (Science Resources Studies, $5 million) part of policy analysis (Policy Research and Analysis), and spending on education research ($10 million). The Department of Education's Office of Educational Research and Improvement has a total budget of about $67 million, which includes among other things funding for libraries, the ERIC database, major surveys, and the National Center for Statistics. Although only a miniscule portion of this is targeted to science and mathematics education, overall data collection includes science and mathematics education. In addition, other mission agencies keep administrative records of their R&D and education programs and spend small amounts on special research and data projects. Of special note are National Institutes of Health studies, including the Institute of Medicine's biennial personnel needs analysis, and the Department of Energy's annual manpower analysis.

SOURCE: Office of Technology Assessment, 1988.

to invigorate the current science and engineering work force by reducing attrition of undergraduate and graduate students. Such short-term retention programs could increase output of scientists and engineers within a few years. In contrast, recruitment is a long-term strategy to enlarge the base of potential scientists and engineers by recruiting more and different students into science and engineering. Such a strategy entails working with schools and colleges, and with children, teachers, and staff to renovate elementary and secondary mathematics and science education.

RETENTION POLICY OPTIONS

If the Nation wants more scientists and engineers relatively quickly, then retaining undergraduate and graduate students in science and engineering is the most useful policy strategy. Many able students leave science and engineering during college, after earning baccalaureate degrees, and during graduate school. Only about 30 percent of B.S. science and engineering graduates enter full-time graduate study, and nearly half of science and engineering doctoral candidates never earn Ph.D.s. Some loss is inevitable (and, indeed, beneficial to other fields), but those who leave unwillingly and prematurely are a rich resource that could be tapped. Because attrition rates are so high and the population of research scientists and engineers is relatively small, slight improvements in retention could increase significantly the number of scientists and engineers in the work force. Federal policies could work at all levels to retain more of these able, interested students in the pool.[2]

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[2] Although "scientists and engineers" are addressed categorically throughout most of this chapter, there are differences between them that demand separate policy consideration. Potential scientists aim for doctoral degrees, but most engineers enter the work force with a baccalaureate degree. Some engineers either continue immediately, or re-

Many factors affect students' career choice and persistence in science and engineering: interest and aptitude; perceptions about careers gleaned from university faculty, peers, and summer jobs; and anticipated earnings and nonmonetary rewards. Students considering academic careers must also weigh the burden of undertaking and financing graduate training. The Federal Government affects these career decisions through targeted support of students, universities, and research, and through its pervasive influence on the American economy and research agenda. The extent and form of Federal support for students, particularly graduate students, affects the attractiveness of further study. Federal R&D support and national research missions (e.g., in health, space, defense) shape students' perceptions of the job market for scientists and engineers, as well as the environments in which students are educated.

Many of the policies discussed below involve established mechanisms that could be expanded effectively. There is an adequate reserve of prepared college graduates and graduate students who, with the proven incentives of fellowships and potential R&D-supported jobs, would be able to shift their career choices.

1. Support Graduate Training

The Federal Government is the most important source of direct support for graduate training, primarily through fellowships and traineeships, and of indirect support through universities (which pass on money to students through research assistantships). This support is intended to meet national research and education needs by making graduate study attractive to baccalaureate recipients, and sustaining those who enter graduate school through completion of their Ph.D.s. To achieve these goals, the Federal Government can adjust the overall level of support, distribute money among different forms of support, and vary the relative amounts of support given different categories of research, such as basic research and mission R&D, and different categories of students and institutions.

- Expand graduate fellowships and traineeships.
- Shift distribution of student support among the major forms of support: fellowships, traineeships, research assistantships (RAs), teaching assistantships (TAs), and loans. (Currently the bulk is in RAs.)
- Shift distribution of graduate student support between the National Science Foundation (NSF), the Department of Education, and the mission agencies. Authorize mission agency support for graduate training in those agencies not currently authorized.
- Expand special support programs for minorities and women.
- Expand postdoctoral fellowships and traineeships.
- Clarify tax status of graduate student stipends and support.

Federal support of graduate training is a proven, highly effective means of producing scientists and engineers. Federal influence at the graduate level is relatively straightforward: the support (Federal and otherwise) available for graduate students influences the number of students pursuing and earning Ph.D.s and directs them toward funded research areas. Different support mechanisms—RAs, TAs, fellowships, and loans—support students in different stages and aspects of their graduate study. This diversity of support mechanisms has served U.S. universities, students, and research well. The Federal Government has directed its support to an array of RAs and fellowships, and to training grants that benefit both universities and students.

The allocation of Federal support among these different mechanisms depends on the purposes sought. For example, if the Federal Government wanted to encourage teaching as a career, it might support more TAs. Currently there is little Federal funding of TAs, which total only about $3 million annually. Fewer than 400 full-time graduate students, or 0.1 percent, receive their primary support from Federal TAs. If increasing the research experience of women and minority students is a goal, then they could be targeted for RAs funded by Federal research grants to faculty (see below). Few arguments are mounted against Federal support of graduate students, particularly in areas where there is clear na-

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turn after gaining work experience, for a master's degree. Traditionally only a small number have sought Ph.D.s and these engineers have most often taken an academic position. Scientists are more likely to enter academia and other nonprofit environments. This chapter concentrates on the research work force, the subset of scientists and engineers most likely to have Ph.D.s. Unless otherwise specified, reference here to scientists and engineers means *research* scientists and engineers.

tional interest, such as biomedicine, space sciences, environmental science, and basic academic research. The most controversial issues are the overall level of support and the allocation of training support among different types of students and institutions.

Fellowships and Traineeships.—Fellowships and traineeships are the cream of Federal support. Fellowships provide flexible, generous support directly to a few of the very best graduate students, and promote successful, rapid completion of Ph.D.s. Multiyear training grants are awarded to institutions, which in turn distribute traineeships to graduate students. Traineeships provide valuable support for the university's education and research infrastructure. Training grants are a proven means of nurturing students who will become successful researchers. Together, fellowships and traineeships are effective, long-term, and low-risk investments in a core of creative graduate students and future researchers.[1] Expansion is possible; field-specific fellowships and traineeships offered in the 1960s, under the National Defense Education Act, helped spur unprecedented increases in science and engineering graduate enrollments and Ph.D. awards.

Current Federal fellowships and traineeships total about $250 million per year and provide primary support for about 13,300 (or 5 percent) of full-time graduate students. Training grants form the bulk of this support ($170 million annually, which supports about 9,000 or 3.7 percent of full-time graduate students). The single most important source is the National Institutes of Health (NIH) National Research Service Award traineeship. Fellowships alone total $80 million annually, which support just 1.6 percent of full-time graduate students.

Fellowships and traineeships may be field-specific. One risk of increasing field-specific predoctoral and postdoctoral support is the national waste and personal cost of training students in fields with changing research priorities that undermine the job market (as in environmental sciences or renewable energy in the mid-to-late 1970s). However, such changes are difficult to predict. The best alternative is to encourage close monitoring of the labor market by Federal funding agencies, universities, and industry employers; to encourage universities and students to shift fields of study where the job outlook is bleak; and to help graduate students, new Ph.D.s, and young researchers move to neighboring specialties as necessary.

"Portable" fellowships (awarded to individual students who carry them to the institutions of their choice) tend to reinforce concentration of Federal R&D support in the best, well-established university departments. The advantage of fellowships is great for students and institutions, since they are flexible and generous, and produce both good research and Ph.D. researchers.

Traineeships and grant-linked research assistantships direct Federal support to a broader range of institutions. Because of the many years needed for graduate training and the resulting delay between fellowship awards and completion of Ph.D.s, no form of graduate support can address short-term personnel shortages or urgent research problems. Graduate students, however, seem to respond more quickly to increases in support than to decreases.

Fellowships and traineeships are particularly effective for attracting and nurturing minorities and women. Expansion of fellowship support is limited by the relatively small numbers of minorities who pursue graduate study; many more qualified women B.S. graduates, however, could be attracted. Currently, there are few such special programs in place; an exception is the widely-acclaimed Minority Access to Research Careers program of NIH. NSF awards about 50-75 graduate fellowships annually to minorities; the Department of Education offers minority fellowships which, although not targeted to science and engineering, are used by graduate students in these fields. Several other mission agencies have small programs that typically provide fellowships for 5 to 30 minority graduate students. In all, special Federal fellowship/traineeship programs for minorities total about $8 million to $10 million annually and fund about 100 to 150 graduate students (only a few percent of minority graduate students). Doubling special fellowship programs for minorities and establishing similar programs for women at the same level would require about $30 million dollars annually. Such funds could be set aside from existing fellowship programs, or additional funds could be appropriated.

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[1] Because fellowships and traineeships are usually awarded to the best students, it is difficult to say to what extent the form of support enhances graduate education and to what extent the better student would excel anyway. Undoubtedly, both the high quality raw material and the generous support are important. The complete fellowship and traineeship system, including promotion, selection, and the support itself, is effective.

Postdoctoral fellowships, generally 2 years in duration, augment the specialized knowledge and skills acquired during graduate study. Postdoctorates are particularly productive, creative researchers, because they can devote themselves to research full time. They are a reservoir of talent that fellowships can rapidly and efficiently guide toward current research priorities. Postdoctoral appointments also help retain Ph.D.s in the research work force, especially in slack job markets, and help shift researchers toward current priorities. Current Federal support is approximately $150 million per year, mainly in the life sciences, supporting about 5,000 postdoctorates (23 percent of all postdoctorates). Another $250 million or so per year supports about 11,000 postdoctoral students through research grants.

Taxation of Graduate Student Aid.—The tax status of graduate student aid has changed in the past few years with changes in tax law.[4] The guiding principle of the 1986 tax reform was to minimize special exemptions (e.g., student aid), while minimizing the burden by reducing the overall tax rate.[5] The general trend has been to reduce tax exemptions on student aid, both stipends for living expenses and aid to cover tuition fees. Currently, all forms of student aid—TAs, RAs, fellowships, and traineeships—are considered taxable income. Recent tax reform affirmed in legislation the taxable status of student aid, but both the tax code and its enforcement remain murky. There are varying interpretations of whether all forms of aid—from TAs, which are given for providing teaching services, to fellowships that have no formal work requirement—are covered by the same laws and taxed similarly, and whether aid that goes to tuition should be taxed in addition to stipend aid.

Most agree that tuition aid should not be taxable. However, there are concerns about scope and implementation. The financial attractiveness of graduate study is tenuous, given the low earnings of most graduate students; increasing withholding and students' eventual tax burden without a compensating increase in stipend could deter or lengthen graduate study.[6] To sustain the current level of support, Federal and other contributions for student aid would need to be increased. To compensate for the added tax burden on the recipients of their awards, NSF and other agencies are seeking to increase their allocations. This step would simply maintain the current levels of student and institutional support. States and universities would need to boost institutional support to maintain TAs and other forms of aid.

Confusion and some unanticipated problems have arisen from lack of coordination between tax legislation, the Employer Assistance Act, Internal Revenue Service regulations, and student aid legislation and regulations. Congress could clarify the tax status of tuitions and stipends, and set out in a separate section of the tax code the tax liability of each form of student aid.

2. Sustain Academic R&D Funding

The Federal Government is the Nation's R&D pacesetter. Its $60 billion annual R&D budget is about half of U.S. R&D, and influences the rest substantially. Federal R&D funds are even more visible on campus, where they support nearly two-thirds of all R&D.

R&D spending not only helps develop scientific and technological knowledge that is useful to national needs, but also has important and often underappreciated effects on the education of scientists and engineers (see table 4-3). First, the overall level of R&D spending, as well as its distribution among

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[4] This section is based on personal communications with Bob Lyke, Congressional Research Service, February 1988, and Tom Linney, Council of Graduate Schools, February 1988. Also see Stacy E. Palmer, "Measures To Tax Scholarships Pose Dilemma for Graduate Schools," *The Chronicle of Higher Education*, Apr. 16, 1986, p. A1; and Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need to Know* (Washington, DC: American Association of Universities, 1986), pp. 62-64.

[5] The main goal of the original post-World War II tax exemptions for student aid was to encourage college attendance. This goal has clearly been achieved for undergraduates where the financial burden rests with students and their families. Given the weak market incentives for graduate study, there still seems to be a need and national justification for special financial buttressing of graduate study (for which educational institutions and Federal and State Governments have traditionally paid).

[6] A related consideration is unanticipated or inequitable impacts of the tax law on certain groups, particularly foreign students and married students. Foreign student aid is withheld automatically at the highest rate, and they receive no deductions for children. This may discourage foreign graduate students and does nothing to increase the numbers of American students.

Table 4-3.—Annual Federal Support of Graduate Education and Research
($ = approximately $75 million)

Most Federal research-related funds that go to universities support current R&D, rather than the education of future researchers. Research support also is the largest source of Federal support for graduate education; research assistantships from university research grants and contracts support over three times as many graduate students as do direct Federal fellowships and traineeships.

Primary purpose:	Education	Research
Category of support:		
Individual student support (fellowship)	$	
Training support	$$	
Institutional development	$$	$$$$
R&D support	$$$$$$ (RAs)	$$$$$$$$$$$$$$ $$$$$$$$$$$$$$ $$$$$$$$$$$$$$$ $$$$$$$$$$$$$$$ $$$$$$$$$$$$$$$

KEY: RAs = research assistantships.

SOURCE: Office of Technology Assessment, 1988.

fields and missions, both directly shapes the job market for scientists and engineers and is the single most important predictor of their future supply.[7] Second, the portion of Federal R&D spending that goes to fund science and engineering research on campus helps support large numbers of RAs, which are the most common form of Federal graduate student support.

Changes in national R&D policies affect both the attractiveness of the science and engineering career as well as the ease with which students can prepare for one. Currently, over one-quarter of Ph.D. recipients have federally-funded research assistantships during their graduate study, a mechanism that provides about $500 million in annual student support. The vast majority of this spending comes from the mission research agencies, which provide about $5.5 billion in academic research support annually. About 30,000, or 12 percent, of graduate students receive their primary support from RAs annually. Overall, about 5 to 15 percent of research funds awarded to university investigators is spent on RAs, with this proportion varying significantly by field, Federal agency, and the purpose for which the funds are provided.

- Recognize the educational as well as the scientific benefits that accrue from Federal R&D support to colleges and universities.
- Shift the distribution of Federal R&D support among academia, industry, and government,

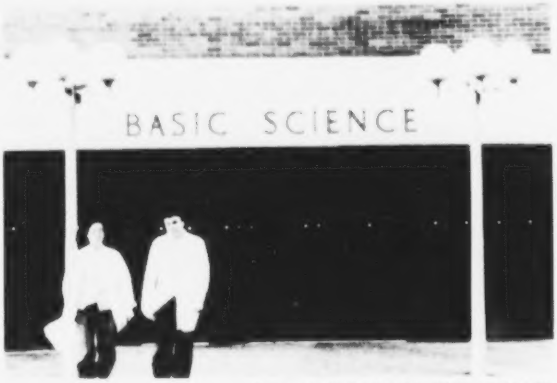

Photo credit: National Institutes of Health

Federal research and development funding bolsters and guides demand for scientists and engineers, graduate students as research assistants, and the universities and colleges that train future scientists and engineers. National Science Foundation support of basic scientific research forms the backbone of education and research in science and engineering. But the Federal mission agencies provide, overall, more funding, and dominate funding in fields related to their mission. Striking the balance between these two routes of Federal support never has been easy.

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[7] Lewis C. Solmon, "Factors Determining and Limiting the Supply of New Natural Science and Engineering Baccalaureates: Past Experience and Future Prospects," prepared for the National Science Foundation Workshop on Science and Engineering Manpower, draft manuscript, July 8, 1986; Eli Ginzberg, "Scientific and Engineering Personnel: Lessons and Policy Directions," *The Impact of Defense Spending on Nondefense Engineering Labor Markets*, A Report to the National Academy of Engineering (Washington, DC: National Academy Press, 1986).

taking account of the different educational benefits that derive from spending in each of these areas. Consider shifting the balance of R&D spending between defense and civilian areas, and among basic, applied, and development-oriented programs, in light of their different educational effects.
- Increase overall R&D support as a way of improving the attractiveness of science and engineering careers and expanding the research work force.

Research Assistantships and the Mission Agencies.—In general, RAs provide vital bench research experience in state-of-the-art university research programs. Next to fellowships, they are the most sought-after form of graduate student support. Designating RAs for women and minority students encourages persistence to the Ph.D. and is thus a tool for altering the composition of new entrants to the science and engineering research work force.

Most RAs are provided through funds from NIH; its expenditures on health and biological research dwarf the total spending of NSF and many other agencies. Among other mission agencies, the Department of Defense is a prominent funder of engineering and mathematical research, the National Aeronautics and Space Administration dominates space science, the Department of Energy is prominent in energy and physics research, and the Department of Agriculture is a major funder of agricultural research. In some fields (such as geodesy, space science, and high-energy physics), the respective mission agency is the only supporter of research; it seems reasonable that each agency look after its own research work force as well. NSF, however, is entrusted with Federal support of basic research relevant to the general interests of the Nation rather than any particular mission. Overall, four of five federally supported full-time graduate students are funded through the mission agencies.

One consideration in assessing the allocation of funds among the agencies is the variable proportion of academic research funds from each agency that goes to RAs. For example, the proportion is much higher for NSF grants than for those from the Department of Defense. In general, a greater proportion of academic, civilian, and basic research funding (as it is variously labeled) goes to support students than does defense and development funding.

Closer educational links could be forged between academia and the mission agencies' own laboratories. Mission agencies could be encouraged to fund programs to provide graduate training (via fellowships or internships) for students at their laboratories. Such programs would improve the dissemination of students' research, help the laboratories to recruit talented students, and improve relations with universities. In some cases, the relevant legislation governing each agency's research activities might have to be amended to permit such programs to be established.

3. Control the Flow and Retention of Foreign Students

The vitality of U.S. universities attracts increasing numbers of foreign science and engineering graduate students and visiting scholars, many of whom stay in the United States after completing their degrees. In engineering, more than one-half of all graduate students and more than one-third of new faculty are foreign.

The unprecedented visibility and even predominance of foreign citizens in certain fields has raised concern. Most observers see the problem as a shortage of Americans rather than a surfeit of foreign scientists and engineers. (U.S. graduate students in engineering increased by 20 percent for 1975-85; foreign graduate students in engineering increased *even more*. It is important to look at absolute numbers as well as proportions.)

Immigrants make valuable contributions to U.S. research. They are highly selected, academically competent, and valuable researchers who have maintained many university departments as American student and faculty numbers have slowed. Student entry is now the dominant path of immigration for scientists and engineers. Relying on foreign talent in key areas is seen to have many drawbacks. Some consider foreign students and faculty as a national security risk; others cite their difficulty in "fitting in," owing to language and cultural differences; and some worry that they drain talent from their home nations.

- Encourage Americans to undertake graduate study and academic careers in selected fields.
- Continue the selective entry and immigration of educated, skilled foreign scientists and engineers.
- Use immigration and naturalization policies, financial support eligibility, or employment regulations to open or close the doors to foreign students and/or immigrant scientists and engineers.

Apart from the widely accepted goal of encouraging American graduate students in science and engineering, a fundamental issue is whether to encourage foreign students and workers, or to restrict them. These people add skills, creativity, and energy to U.S. science. Although the greatest contributions are likely to come from immigrants who stay permanently, temporary visitors and graduate students also contribute to U.S. research while they are here. Furthermore, even after visitors leave they usually maintain contacts within the U.S. research community. Several mechanisms are available to broaden, selectively encourage, or restrict the entry, length of stay, and permanent immigration of scientists and engineers.

Most suggestions to encourage American study in fields with high proportions of foreign students, such as engineering, mathematics, and computer science, center on one tactic: increasing RA or TA stipends to make graduate study more competitive with employment, usually setting the target figure at half the average starting bachelor's-level salary. Similar measures have been used with young faculty members; universities have supplemented faculty salaries in competitive fields such as engineering, business, and medicine. This step can create jealousy on campus. In some cases, the supplements have been temporary, until the labor markets have adjusted and more Americans take faculty posts; in other cases, separate salary scales for faculty are instituted.

Most foreign scientists and engineers originally came to the United States as students (on temporary or nonimmigrant visas). Those who stay usually obtain visas as temporary workers (H-1 or H-2 temporary visas); under current Immigration and Naturalization Service (INS) policy, these visas are generally good for 5 years, renewed annually on the basis of continued need by employers. Some workers apply for permanent visas, with the sponsorship of employers, by a process known as labor certification. Graduate students who stay on are the largest source of permanent foreign entrants to the science and engineering work force. Direct immigration of experienced scientists and engineers is much less common and less of a policy issue.[8]

The Federal Government could use eligibility constraints to expand or restrict support of foreign students. Most Federal fellowships are not open to foreign citizens; the cost of graduate education for foreign science and engineering students must be defrayed by support from their home countries or the U.S. universities they attend. Making foreign citizens eligible for fellowships would allow agencies to recruit people in fields where American students are scarce. Another option is to restrict foreign eligibility for research or teaching assistantships, which would depart from the tradition of faculty autonomy in selecting assistants and deter many good foreign students from U.S. graduate study.

Other mechanisms include:

- Changing the approval criteria for labor certification.[9] The Federal Government could encourage foreign nationals in science and engineering to stay in the United States by eliminating the requirement for labor certification altogether.
- Changing the regulations that require students who have held exchange visitor (J-1) visas to return home before applying for a permanent visa. Extending this requirement to all students

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[8] Perhaps 150,000 foreign science and engineering students enter each year, mostly on temporary student visas (F-1), some on exchange visitor visas (J-1). They favor fields with rapid employment growth such as computer science and engineering, as do American graduate students. Under current policies, students can apply to extend their visas for 1 year of practical training, and then convert to a temporary worker visas (H-1 or H-2) for up to 5 years. In 1985, about 12,000 foreign science and engineering students (or former students) converted to permanent visas, while about 5,000 immigrants in science and engineering occupations entered the United States. In addition, some students on temporary visas stay and work. Overall, about half of foreign graduate science and engineering students stay in the United States to work for a number of years. Dennis Keith, Immigration and Naturalization Service, personal communication, Jan. 29, 1988.

[9] About 30 percent of immigrant scientists and engineers receive an employer-submitted labor certification, which demonstrates that the Secretary of Labor has determined that the job cannot be filled by a U.S. worker and that employment will not adversely affect U.S. workers similarly employed. The Immigration and Naturalization Service then has to consider the individual's petition for immigration (on the basis of quotas and occupational preferences).

and/or to temporary workers would probably reduce both permanent immigration and student entry by decreasing the attractiveness of university study as a simple means of permanent immigration.

- Controlling the number of student and temporary visas issued by INS and the Department of State, possibly by field (currently there are no quotas). Such a measure would likely reduce the number of foreign students.
- Further restricting entry according to country of origin or field, thus reducing the number of immigrant scientists and engineers. In addition, certain occupations are exempted from certification; expanding this list could impose occupational preferences for immigration quotas.

4. Support Institutions That Make Special Contributions to Undergraduate Science and Engineering Education

Graduate education builds on the base laid by undergraduate education—the 4-year period in which the student pursues coursework in the fundamental subjects of science and engineering, may actively work in research projects, and first encounters faculty mentors who are research professionals. Although the Federal Government does not support undergraduate education in the same direct way as it does graduate education (primarily via research grants), it does provide considerable indirect funding. The routes by which these funds are supplied include overhead on research grants and student awards, and programs for improving institutional development, instructional equipment, libraries, and facilities. Much of this funding is not specifically directed to science and engineering education, although it does benefit these fields.

The bulk of this support goes to a small number of elite research universities, which graduate most of those who go on to science and engineering careers. Yet the large scale and research orientation (often at the expense of teaching) of these institutions may deter others from considering graduate study. There are other, smaller institutions that are strong in undergraduate science and engineering without having the research focus of the research universities. These smaller institutions, such as research colleges, historically Black colleges and universities (HBCUs), women's colleges, and primarily engineering institutions, in fact graduate large numbers of science and engineering students who go on to further study in these fields.[10] These successful, and often neglected, undergraduate environments may merit special Federal support, and certainly provide lessons that could be adapted to other institutions, including the research universities. sities.

- Expand research, student, or institutional support of institutions that are especially productive of baccalaureate degree recipients who become science and engineering Ph.D.s. Doubling current special programs for research colleges would require $10 million to $20 million annually. Doubling current support for minority institutions would require $500 million to $750 million annually.

About 100 research universities train the vast majority of science and engineering Ph.D.s. They also produce most of the bachelor's recipients in these fields who go on for Ph.D.s. They receive nearly all of Federal academic R&D funds and are well-endowed; few argue that they need new Federal funding. Some observers contend, however, that they neglect undergraduates in favor of research and graduate training. Yet the academic reward system, based on success in research, is largely impervious to change. Institutions might be more productive of undergraduates if faculty were encouraged to pay attention to teaching through mechanisms that shift funds toward mentor grants and undergraduate research participation, or if research funds were somehow tied to overall teaching performance.

The research colleges—small, 4-year liberal arts colleges that concentrate on science and research—are especially effective in educating and encouraging students who go on to be research scientists. Observers attribute this success to their emphasis on teaching, programs that prevent attrition, student research participation, and continuous personal contact between faculty and students. Current Federal support for research colleges rests with NSF, with programs supporting special instructional equipment and research. NSF's College Science Instrumentation Program is currently funded at $10 million per year. Less than $35 million, or 0.5 percent of Federal academic R&D funding, goes to the research colleges annually. Special programs could provide equipment and facilities for teaching and research, coordinate research and education activities that result in significant student participation in faculty research at the research colleges, and promote cooperation and resource-sharing among small colleges, and between small colleges and universities.[11]

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[10] A large category of institutions omitted from this list are the comprehensive universities. Seventy percent of these 600 institutions are State schools. They represent a point of access to higher education for many students who either do not qualify for or cannot afford more selective institutions. Some believe that their role in undergraduate science and engineering education, and as a feeder of the research universities, could also expand if resources to meet the same instrumentation and faculty needs of other teaching environments were made available. See Philip H. Abelson, "Science at the Four-Year and Master's Universities," *Science*, vol. 239, Feb. 12, 1988, p. 705.

HBCUs, numbering about 100 and located predominantly in the South, graduate about one-third of all Black bachelor's recipients. HBCUs have long received special Federal support, dating from legislation to ensure minorities' access to higher education. These institutions send many of their graduates on to Ph.D.s in science and engineering. HBCUs provide a supportive intellectual and social environment that heightens minority student retention and sparks graduate study. In addition to HBCUs, with their special legislative status, there are several hundred 2- and 4-year colleges with predominantly minority enrollments, including a growing number of institutions with large Hispanic enrollments. These institutions have underutilized potential for nurturing science and engineering talent.

Total Federal support of HBCUs is about $700 million per year, most of it general institutional support. Funds for equipment, facilities, faculty exchanges and development, educational materials, and various student services are awarded by the Department of Education (about $630 million under Title III of the Higher Education Act and $5 million under the Minority Institutions Science Improvement Program).[12] Little of the support under Title III has been directed at science and engineering. NSF, NIH, the Department of Agriculture, and other mission agencies have smaller, more informal programs that benefit HBCUs.

Setting aside special support for some group of institutions can be politically controversial. To what extent should existing productive environments be supported, and how much effort should go into identifying and reproducing the characteristics that foster productivity? A related question is whether more support would automatically make scientist- and engineer-producing institutions even more productive. Some have argued, for example, that funding large amounts of research (instead of teaching) at research colleges could undermine the emphasis on teaching. Federal initiatives such as the NSF Science Development Program have worked, although they are expensive even when costs are shared by State and private sources of funding. There is substantial inertia in the structure and culture of individual colleges, and in the overall hierarchy of institutions.[13]

5. Expand Undergraduate Hands-on Research Experience

Research experiences in actual research settings provide science students with valuable previews of scientific research careers. These programs take many forms—formal cooperative arrangements, apprenticeships, field work, undergraduate research fellowships and teaching assistantships, summer jobs, and internships. Extensive testimony and some re-

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[11] The 1987 Oberlin Report calls for a 10-year investment of $1 billion, half for "maintenance and enhancement of effective teaching and research" (e.g., faculty and student grants, and new instrumentation), 15 percent for construction and renovation of laboratories and classrooms, and the rest for additional faculty positions. See Sam C. Carrier and David Davis-Van Atta, *Maintaining America's Scientific Productivity: The Necessity of the Liberal Arts Colleges* (Oberlin, OH: Oberlin College, March 1987), p. 133.

[12] James B. Stedman, Congressional Research Service, Library of Congress, "Title III of the Higher Education Act: Provisions and Funding," issue brief, Mar. 31, 1987, pp. 4-6. Also see Margaret Seagers, Executive Director, White House Initiative on Historically Black Colleges and Universities, in U.S. Congress, House Committe on Science, Space, and Technology, Subcommittee on Science, Research and Technology, *Federal Science and Technology Support for Historically Black Colleges and Universities* (Washington, DC: U.S. Government Printing Office, Oct. 9, 1987), pp. 197-209.

[13] Another concern is whether funding special environments, such as women's and minority colleges, would perpetuate undesirable separate education and preserve an artificial "hothouse" environment that nurtures students while they are in it, but does not prepare them for mainstream research later. (There is some indication, for example, that women baccalaureates from women's colleges, while they are more likely than women from coeducational institutions to earn a science or engineering Ph.D., are less likely to continue in research careers.)

Photo credit: Carl Zitzmann, George Mason University

Undergraduate research participation can be a highly effective way to encourage undergraduates to consider entering graduate school and becoming research scientists or engineers.

search data suggest that students who participate in undergraduate research are more likely to become productive scientists.

Engineering students planning to enter the work force with B.S. or M.S. degrees have a similar option in cooperative education. Cooperative education students alternate their regular academic studies with paid jobs related to their major, usually off-campus in industry or government. The work experience gained in a cooperative program—as in other summer or part-time work related to a student's major or in research projects for science students—provides early exposure to a planned career and a valuable head start on "real-life" workplace skills. Formal cooperative programs encompass only about 2 percent of science students and 10 to 15 percent of engineering students.

- Increase funding for undergraduate research by NSF and possibly the mission agencies, as special programs or supplements to research grants.
- Target women or minorities.
- Increase support for cooperative education (fund university programs, provide incentives to employers, and encourage Federal agencies to host more cooperative education students).

A line-item addition to grants could reward investigators and institutions for involving undergraduates, especially women and minorities, in research projects. NSF has built such an incentive into some of its research programs, and it could expand the effort. Adding student participation in research as a criterion when evaluating applications for support (or even accreditation) would raise consciousness about experiences that are critical to budding research careers.

Current annual Federal support of undergraduate research is in the $15 million to $100 million range, involving 7,000 to 12,000 undergraduates. NSF leads with a dedicated program, Research Ex-

Photo credit: University of Tulsa and The Chronicle of Higher Education

Cooperative education programs combine academic coursework with periods of off-campus industrial training. They give students valuable early exposure to "real-life" work skills, and help employers find and prepare students for employment after graduation. The Federal Government supports cooperative education programs both through its mission agencies and through a grant program from the Department of Education.

perience for Undergraduates ($9 million annually and 2,000 students). Other research, education, summer research, and outreach programs in NSF, NIH, and mission agencies generally, also involve undergraduates in special programs.

Federal support of cooperative education has included financial support to universities to set up and administer cooperative programs, incentives to industry, and the hosting of cooperative students by Federal agencies. Support under Title VIII of the Higher Education Act has helped universities establish and expand cooperative programs. Current Federal support is $15 million per year under Title VIII for nearly 200,000 undergraduates in cooperative programs at several hundred institutions.

The main argument against expanding support of undergraduate research and cooperative education programs is the cost. Beneficial undergraduate research and cooperative study demands commitment to education by employers. Many employers are reluctant to invest in short-term apprentices, and this resistance limits the attraction of their participation in cooperative education without additional external funding.

6. Target Support for Undergraduate Science and Engineering Students

The Federal Government has expanded access to higher education for most Americans. College enrollments increased rapidly in the late 1960s and early 1970s as the baby boom generation grew up. With the help of Federal aid, especially programs authorized by the Higher Education Act of 1965, a larger proportion of high school graduates went on to college. Federal and State financial aid has been awarded primarily on the basis of financial need, regardless of the planned or declared major of the student.

- Link part of existing need- or merit-based college student aid programs (for example, Pell Grants) to field or institution of study. Certain groups, such as women, minorities, or talented and disadvantaged students, could be targeted.
- Create new programs to support science and engineering students regardless of need.

Federal financial aid is a powerful lever on students aspiring to college educations. This lever could be used to influence the field distribution of undergraduates. The tradition of egalitarian aid based on need and respect for individual choice, regardless of institution and field of study, must be weighed against the possible national benefits of directing more or selected students into certain institutions or fields (for equity, personnel, or institutional development goals). Federal aid linked to field is accepted as necessary support of graduate students and as a way to meet national needs; field-linked personnel training (at both the undergraduate and graduate levels) as a justification for Federal involvement can be traced to the Morrill Act.

There is a circularity to the Federal role in career choice and market demand: indirectly the Federal Government affects the market, without affronting individual freedom of choice. Should it explicitly set priorities on the supply side as well? One option might be for any or all agencies that support college students—Federal, State, or private—to award some or all need-based aid by planned or declared field of study. Congress might direct the Department of Education to consider field of study in offering and awarding need-based aid. (NSF's undergraduate programs already do this to some extent, but they are merit- rather than need-based, and very few in number.) This might be done in the junior or senior year, when fairly reliable near-term market demand for those students can be projected. However, most students will have made their choices of major by this time.[14]

RECRUITMENT POLICY OPTIONS

The basic goal of recruitment is to expand and improve the talent pool. The years to do this are elementary school through the first few years of college. A particularly critical time is 6th through 12th grade, when course-taking becomes more specialized and career plans are formed. Policies to expand the mathematics and science talent pool differ from those to accelerate or improve the education of a small core population. Students who take early, enthusiastic likings to science and mathematics can be served differently from those whose interests are still developing.

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[14] The most prudent course would be to adjust aid at the broad field level (that is, science and engineering versus other fields) rather than to specific fields of science or engineering. The former builds a stock of human resources; the latter favors certain disciplines and skills within the stock.

For all students, the content and quality of their elementary and secondary education determine their academic preparation for college, their likelihood of entering college, and their ability to derive the greatest benefit from a college education. Better high school graduates mean better college graduates, and ultimately better scientists and engineers. Significant changes must occur in students' early preparation, awareness, and interest before they are drawn into college and science and engineering majors, and eventually to graduate and R&D programs. The continuing low participation in science and engineering of women and minorities indicates that the current educational system and career incentives must be made to work better.

There are two demonstrably successful ways to recruit young people to science and engineering: give special science and mathematics enrichment programs to selected students, and give all students good, enthusiastic teaching. An area of lively innovation is informal education—science museums, television programs, camps, and other experiences outside the formal school system.

In the near term, policies must work with existing teachers, schools, textbooks, and equipment, in a system with multiple educational objectives. Truly significant change is difficult to achieve incrementally. In the longer term, substantial improvements in recruitment might come through full-scale revision of elementary and secondary curricula, tracking, testing, and course structure. Such sweeping change should be undertaken with all students and all purposes of education in mind (not just science and engineering), but would be hard to achieve given the scale of American education and the inertia of the existing system.

1. Encourage Intervention Programs

"Intervention programs," within or outside of schools, can increase participation in science and mathematics by raising students' interest, opportunity, and academic readiness for science or engineering majors. Such programs are especially useful with students at greater risk or disadvantage in regular classrooms and curricula.

Most effective programs involve learning science by doing, rather than through lectures or reading; working closely with small groups of other students; contact with attentive advisors, mentors, and role models who foster self-confidence and high aspirations; and exposure to career information. Most programs work at the junior high and high school levels. Many have great success in sending participants on to college and to science and engineering majors. Programs vary greatly in duration, intensity, and expense; they range from full-time summer research projects to occasional career seminars. The goal of most college-level programs is to help students complete their chosen science or engineering degrees. In addition to peer support and academic enrichment, college-level programs often sponsor scholarships, jobs, or research related to participants' majors.

- Fund new, ongoing, and expanding intervention programs for students defined in various ways: female, minority, learning disabled, handicapped, gifted, and talented.
- Encourage private investment in intervention programs, with matching incentives for Federal, State, and local government participation.
- Encourage Federal research agencies to participate in outreach programs.
- Gather and disseminate information on intervention and on its lessons for formal education.

The often impressive success of intervention programs argues strongly for Federal financial and other support. These programs are labor-intensive, but not extremely costly. At the precollege level, annual budgets are usually several hundred dollars per student. College-level intervention programs, often including costs for scholarships, may budget as much as several thousand dollars per participant. They are easy to mount and evaluate on a trial basis, but rely heavily on gifted and determined teachers. The main issues are the extent to which funding intervention programs "compete" with funding for regular education; where and to what extent Federal support is warranted, given the extensive State and private activity; and the groups to be targeted.

Most intervention programs serve limited populations, especially the needs of girls and disadvantaged minority children.[15] A few enrich the education of "academically gifted" children, traditionally a fertile source of scientists and engineers. Greater investment in gifted students would likely increase the quality and quantity of science- and engineering-inclined students. Broadening the ways "giftedness" is defined could produce a more intellectually diverse pool of students than is presently created by the use of aptitude tests. A possible Federal role is to help identify students who could benefit from special programs, but who are not being served, and then to let the interventions take over. Most intervention programs reach only a few students; a local program may reach 30 to 150 students each year. A few of the most successful programs have received substantial support from State governments and foundations and have expanded their reaches statewide, and in some cases nationwide, to thousands of students.

Intervention cannot compete with or replace the regular classroom. The long-term goal is to change the mainstream school system so that it promotes success for all children in science and mathematics. Intervention programs can exist side by side with diverse public and private schools, providing alternatives, experiments, and enrichment outside the classroom, as well as offering lessons for improving formal education.

2. Bolster Elementary and Secondary Teaching

There are no substitutes for good teachers. Education reform depends on getting better teachers and giving them better support, in the forms of curricula, textbooks, mathematics and science supervisors, equipment, preparation time, and training. From kindergarten through graduate school, it is the teacher who inspires or turns off the student.

- Increase support to improve preservice and in-service teacher training.
- Offer financial incentives and other rewards to science and mathematics minority teachers (through awards, forgiveable loans for aspiring teachers, a separate merit pay scale, or supplementary allocations to hire specialists).
- Increase support for enrichment programs for teachers, such as research participation at Federal laboratories.

The quality of teaching and teachers is a perennial issue, as old as American schools. Although all fields need good teachers, mathematics and science face particular difficulties because of the rapidly changing nature of the material, the desirability of augmenting classroom instruction with laboratories, and the stiff competition teaching faces in attracting qualified science and engineering majors away from R&D careers. An imminent problem is a shortage of minority mathematics and science teachers.

A controversy in mathematics and science teacher training is whether future teachers should be expected to have a baccalaureate degree in specialist subjects in addition to some education training. Many elementary school teachers earn baccalaureate degrees in education, with only parts of their programs devoted to specialist mathematics and science courses.[16]

Several groups active in the current reform movement have studied the future of the teaching profession. The Holmes Group (an informal consortium of education deans in research universities) has attached particular priority to upgrading elementary and secondary teachers' subject-specific knowledge by insisting that they have a baccalaureate in a subject area. The group has called for much more subject-specific teaching, and for more subject-intensive preparation of those teachers.[17] Paralleling these developments, the National Science Teachers Association and the National Council of Teachers of Mathematics both require considerable amounts of subject-specific coursework of applicants for their own voluntary certification programs. Most important is the content, not the labeling, of the courses that students training to become teachers take (such as mathematics education), but the long-term trend is to emphasize specific skills for specific subjects rather than an all-embracing "education" approach.

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[15] Attracting and sustaining the *interest* of girls in mathematics is a recurrent theme in many intervention programs. The opportunity to experience mathematics in the presence of other girls seems to change the learning process, remove the stigma attached to excelling in school mathematics, and feed self-confidence and determination. Such a transformation will have to occur if more girls, presently the largest untapped resource in the talent pool, are to entertain the possibility of careers in science or engineering.

[16] For example, virtually all elementary mathematics teachers and elementary science teachers have a degree in a subject other than mathematics or science. At the high school level, however, 40 percent of mathematics teachers and 60 percent of science teachers have a degree in those subjects, and another 36 and 24 percent, respectively, have either a degree in mathematics and science education or a joint degree, i.e., one that combines a mathematics or science field with science or mathematics education. See Iris R. Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education* (Research Triangle Park, NC: Research Triangle Institute, November 1987), table 45.

[17] Holmes Group, Inc., *Tomorrow's Teachers* (East Lansing, MI: 1986). So far, only Texas has reformed its certification requirements in this way. Starting in 1991, new entrants to the profession will need

Two issues face the Federal Government: to what extent and on what basis does it enter the debate over what has traditionally been a State (and local) prerogative; and how does it spend money effectively on what works. A large part of the difficulty facing the Federal Government or any other actor trying to improve teaching is that society does not attach great distinction or reward to teaching. It is not certain to what extent higher salaries, merit pay, and other financial incentives attract and keep better teachers. While some teachers leave teaching because of low pay, many more probably leave because of poor working conditions. Teacher salaries have risen significantly since the education reform efforts of the early 1980s, although they continue to lag other professions. Indications are that with national laments over a teaching "crisis" and "quality," incentives of merit pay and boosts in salaries and responsibility for teachers in many school districts have increased student interest in teaching careers.

The Federal Government has supported, especially through NSF summer institutes, inservice training for mathematics and science teachers. Current inservice training is limited in scale and can do only so much. While the teaching force is well-qualified and informed about the most effective teaching techniques, it often fails to use them. Boring textbooks are widely used in unimaginative ways. Teachers are not encouraged to use techniques such as hands-on science. Teachers' training does not always couple pedagogy to subject knowledge.

The main needs are:

- to determine what makes for good inservice and preservice education;
- to give the current teaching force much more inservice education than it currently receives;
- to give the current teaching force better access to research results and curriculum reform efforts;
- to impose a science and mathematics education requirement on new science and mathematics teachers, as part of State certification; and
- to recognize that elementary and secondary teachers have different problems and needs.

Finally, accountability pressures on teachers must change to encompass process and not just outcomes. "Teaching to the test" has been emphasized in many schools at the expense of broader educational objectives. Schools, teachers' unions, States, school districts, and the colleges and universities that train teachers must share responsibility for measuring accountability.

The Federal Government has some limited influence over teacher training through support for undergraduate education and through NSF programs in teacher preparation and enhancement. Two existing avenues could be used to bolster mathematics and science teaching: Title II of the Education for Economic Security Act ($80 million annually) and National Science Foundation programs ($22 million annually). NSF's Teacher Enhancement Program needs to be expanded and should continue to emphasize science and mathematics pedagogy together with content. Through inservice training and alternative certification, the teaching ranks could be opened to those with mathematics and science expertise who lack teaching degrees.

Current Federal support for inservice training totals about $160 million per year, reaching perhaps 10 to 35 percent of science and mathematics teachers. Other mission agencies reach a small number of teachers through a variety of programs. Additionally, of Federal education block grants for curriculum and staff development, OTA estimates that around 25 percent, or $10 million per year, go to science and mathematics teaching.[18]

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to have both a subject-specific degree and a maximum of no more than 18 course-hours in education. Lynn Olson, "Texas Teacher Educators in Turmoil Over Reform Law's 'Encroachment'," *Education Week*, vol. 7, No. 14, Dec. 9, 1987, p. 1.

[18] In contrast, during the heyday of the National Science Foundation's science and mathematics summer institutes, the 1960s, Federal spending on teacher training was about $60 million annually (in 1960s dollars) and reached, over the decade, perhaps half the science teachers in America.

3. Support Informal Education

Education and exposure to science outside of school offer alternative ways to get children interested in science. By augmenting classroom learning, science and technology centers—at least 150 in the United States alone—are excellent places for motivating interest in science. Science centers also conduct teacher training, especially for elementary science teachers. Many audiovisual techniques, especially science on television, are powerful teaching vehicles. Learning and research projects at camps and science fairs also reach children by offering a variety of sciences that cannot all be explored in the classroom. Together these sorts of experiences are known as "informal education."

- Increase funding of science and technology centers, particularly for education and teacher training.
- Increase funding of science television and other experimental teaching methods.

In terms of the supply of future scientists and engineers, science centers are excellent at motivating, but not at enhancing formal learning. Their contribution is more for enlarging the pool at an early age. Outreach programs are increasing access to science centers by minority and disadvantaged students, and minority teachers.

Current annual Federal support of informal education is about $13 million to $20 million for a variety of programs funded by NSF and the Department of Education. In addition, about $90 million to $100 million per year goes to science-related Smithsonian and National Zoo museum and education programs. Other actors are local communities, States, industry, and museum visitors (who pay to attend). Communities are quite successful at initiating the operation of centers; a possible Federal role is to capitalize on this success for education.

4. Improve Opportunities for Women

Women have made significant inroads into science and engineering over the past 15 years, on the heels of equal opportunity activism and legislation. This progress varies greatly by field; women are a substantial proportion of biologists and social scientists, but are still scarce in engineering and the physical sciences. Overall, women's interest in earning science and engineering degrees seems to be plateauing. This fact causes congressional concern, not only for reasons of equity, but because women could substantially augment the research work force if their interest in research careers burgeoned. Several factors combine to turn women away from science: pervasive, accumulating societal bias at home, in school, and among friends against the notion of girls as good science and mathematics students and against women as research scientists and engineers; difficulty juggling family responsibilities with graduate education and especially research; the disincentives of the often second-rate career opportunities and salaries for women in science and engineering; and weaker academic preparation than men through secondary school and college, particularly in science and engineering (which, to some extent, is a function of the first two factors).

Raising women's interest in science and engineering careers could go far toward compensation for the projected decline in bachelor's recipients in these fields. The research potential of women is great, though they still face pervasive social and economic barriers.

- Enforce more stringently Title IX of the Education Amendments of 1972 and other equal opportunity legislation.[19]
- Support intervention programs for women at all levels.
- Fund special fellowships and undergraduate research opportunities for women.

Federal legislation, in particular Title IX of the 1972 Education Amendments, has provided leadership, law, and most importantly a national commitment to sex equity, and has impelled substantial social and economic changes. Title IX eliminated overt discrimination and encouraged equitable treatment of men and women both inside and outside education. The greatest gains of women in science (and other traditionally male professions) were made during the early days of Title IX, during broad interpretation of the legislation, vigorous enforcement, national leadership, and social fervor.

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[19] Title IX prohibits sex discrimination in education. Other related Federal legislation includes:

- The Women's Educational Equity Act of 1972 supporting dissemination of model materials that promote women's educational equity;
- Title IV of the 1964 Civil Rights Act providing support to States (and originally to local education agencies and training institutes) to comply with Federal laws prohibiting discrimination in Federal programs; Title VII of this act prohibits discrimination on the basis of sex; and
- Carl D. Perkins Vocational Education Act of 1984 requiring States to set aside funds for programs for women.

See Patricia A. Schmuck, "Administrative Strategies for Implementing Sex Equity," *Handbook for Achieving Sex Equity Through Education*, Susan S. Klein (ed.) (Baltimore, MD: The Johns Hopkins University Press, 1985), pp. 119-120.

Since its passage, enforcement of Title IX has lessened, grant support for its implementation under the Women's Educational Equity Act has been reduced, and its applications have been narrowed by Federal and court rulings.[20] Inequitable access and discrimination still exist in education and research, as in the rest of society.

The past clear success of Title IX in reducing discrimination and encouraging women to enter nontraditional fields argues that, to encourage further participation of women in science and engineering, the Nation recommit itself to equity and enforce Title IX and related legislation.[21] Rigorous enforcement is essential to eliminate barriers to careers for women in science and engineering as in other fields. This should require little new funding; most of the achievements of Title IX were made through changes in practice rather than Federal appropriations for new programs.

In addition to sex equity and civil rights legislation, the Department of Education, NSF, and mission R&D agencies also are charged with awarding fellowships and research grants equitably. Equity is part of a Federal package that also includes support of effective programs discussed earlier, especially intervention programs for women at all levels, and special fellowships and undergraduate research opportunities for women.

5. Improve Opportunities for Minorities

In comparison with women, non-Asian minorities (particularly Blacks) have made little progress in science and engineering education and careers. Only in the social sciences and health-related fields are there significant numbers of Black or Hispanic researchers. The civil rights victories of the 1960s and the resulting legislation raised awareness and launched programs, but entrenched social and economic barriers still deter many Blacks. Equal opportunity for participation in higher education and in research for all groups is a long-term social goal that will be achieved only with steady national commitment and investment.

- Enforce more stringently civil rights legislation.
- Expand support of intervention programs, particularly at the precollege level. Redistribute support for intervention programs among the Department of Education, NSF, and the mission agencies.
- Move the Minority Institutions Science Improvement Program from the Department of Education to NSF, which knows how to target and spend "science dollars" fruitfully.
- Support the HBCUs in all ways, from infrastructure to faculty and student assistance.

Title VI of the Civil Rights Act of 1964 prohibits discrimination on the basis of race, color, or national origin in federally-funded programs. Enforcement timetables and procedures by the Department of Education were mandated by *Adams* v. *Califano* (1977), and by *Adams* v. *Bell* (1983), but enforcement by the Department of Education's Office of Civil Rights and the Department of Justice has been lax.[22]

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[20] In 1984, the U.S. Supreme Court ruled in *Grove City College* v. *Bell* that Title IX applied only to the specific program that was federally funded, not to the entire institution that housed the program. Repeated legal challenges from women's and education interest groups have cited lax enforcement of Title IX by the Department of Education. Recent legislation has restored the original intent of the civil rights legislation.

Funding for model education programs under the 1974 Women's Education Equity Act and for technical support for compliance under Title IV of the Civil Rights Act declined substantially in the 1980s. Funding for the Department of Education Office of Civil Rights has declined. See Phyllis W. Cheng, University of Southern California, "The New Federalism and Women's Educational Equity," doctoral dissertation, December 1987, pp. 44-51.

[21] About half the States have laws that cover part or all of Title IX; of these, 13 have broad gender equity laws similar to Title IX. State Title IX officers cite Federal Title IX legislation as more important than State legislation in achieving educational equity. "State sex equity in education laws are merely an addition to existing Federal provisions, not a replacement for them." See Phyllis W. Cheng, Project on State Title IX Laws, Los Angeles, CA, "Can Educational Equity Survive Under the New Federalism?" unpublished manuscript, November 1987, pp. 14, 16.

[22] U.S. Congress, House Committee on Government Operations, *Failure and Fraud in Civil Rights Enforcement by the Department of Education* (Washington, DC: U.S. Government Printing Office, 1987). Also see Scott Jaschik, "Civil-Rights Groups Assail U.S. Ruling That 4 States Comply With Bias Laws," *The Chronicle of Higher Education*, vol. 34, No. 23, Feb. 17, 1988, pp. A1, 24.

6. Invigorate Elementary and Secondary Education

Policy initiatives to modify the structure of elementary and secondary education must be long-term, systemic measures. Reform in several areas—magnet schools, science-intensive schools, curricula and course-taking, tracking, and testing—could substantially improve and extend precollege science and mathematics education. Many have tried to improve education by changing some of its basic components, such as the school calendar, curriculum, teaching practices, class size, textbooks, grade promotion, and structure of the schools themselves. Many of these innovations have benefited the children they reached; much has been learned from the failures as well. However, most education reform makes little lasting difference. Most innovations, such as magnet and science-intensive schools, reach only a few percent of students. Even reforms in curricula and testing, which have the potential to reach all students, in practice reach only a few because of the dominance of the existing course structure and tests. The education system is large, with current practices and incentives firmly established.

The areas discussed here hold great, albeit uncertain, potential for the quality of science and mathematics education. Pursued at their current level and without accompanying changes in the education system that must adopt such reform, they can have only limited impact on limited numbers of students. Realizing the full potential of these reforms would require full-scale renovation of the existing system, from teaching and testing to course structure and content, with the substantial uncertainty and political challenges such an initiative would raise. Such full-scale reform would undoubtedly have unexpected impacts on education, far beyond science and mathematics education. As a result, while such reform is desirable given the dismal state of U.S. elementary and secondary science and mathematics education, it should be pursued incrementally and carefully, but vigorously.

Magnet Schools.—Magnet schools are designed to desegregate school districts by offering special courses of study that attract students of different races. About one-quarter of these special schools emphasize science, mathematics, computer science, and pre-engineering. Magnet school programs are devised and operated by local school districts. They are funded by States and school districts. To support the special costs entailed in the process of racial desegregation, the Federal Government has also funded such programs, but the main actors are States and school districts.

Many science and mathematics magnet schools provide high-quality mathematics and science instruction for those enrolled in them. Many emphasize hands-on learning. Magnet schools probably sustain those students who are interested in science and engineering, and deter those who are not interested. Magnet schools increase the racial and ethnic diversity of science and mathematics students by bringing courses to science-starved areas, and by sorting students by their enthusiasm as often as by achievement. Magnet schools may socially set science and mathematics students apart from the rest to create a climate of intellectual support by peers and teachers. These schools also cost somewhat more than routine schooling.

The Federal Government could promote magnet schools on a basis other than that of racial desegregation (as is already proposed). Promoting magnets would probably improve the quality and variety of students planning science and engineering careers, but would not much increase the number of interested students. Current Federal support of magnet schools is about $75 million annually from the Department of Education, under Title VII of the Education for Economic Security Act, awarded competitively to a very limited number (less than one-half of 1 percent) of the largest school districts.

Science-Intensive Schools and Other Experiments.—The academic environment of special high schools can provide students interested in science and mathematics with excellent educations, and give them early exposure to and encouragement in research careers. They are powerful environments for the few students they serve. Such science-intensive programs and schools are State showpieces, demonstrating the virtue of encouraging the best and most eager. However, they reach only a tiny fraction of students.

Alternative social organizations of schools are also possible. For example, academically-bound students from several high schools could be brought together in one school or during the summer. Universities or community colleges could take over grades 11 and 12, and provide instruction at public expense. It is not clear that Federal support is needed, since States seem to be forging ahead; more appropriate Federal roles might be research and technology transfer.

Course-taking.—Taking advanced science and mathematics courses in high school is crucial to prepare students for science and engineering majors in college. But failure to take such courses in high school should not bar students from later participation in science and engineering. Community colleges and universities are offering more steppingstone preparatory and remedial courses. Such alternative course-taking places additional and generally unwelcome burdens on universities and may unduly discourage course-taking in high school, although the number of college-level high school courses (for example, advanced placement calculus) is rising. Access to such advanced courses by many students, particularly those in inner-city and rural schools, is limited. Finding a better "math path" for the majority of students is essential. Removing the stigma of succeeding in such courses, especially among girls, and linking interest in mathematics with aspirations to a science or engineering career are central to improving course-taking patterns.

Taking more advanced courses (assuming they are taught well) probably enhances the quality and increases the number of students available for science and engineering majors. Imposing course requirements, however, puts a burden on teachers who may not be qualified, and may undermine provision of other good opportunities, such as hands-on experiences.

Access to more courses by more students does not automatically produce more learning or interest. The issue is whether to offer, recommend, or *require* more science and mathematics courses in high school. The proper balance lies somewhere between building on existing interest and fostering it through mandatory exposure.

Recognize the Strengths and Weaknesses of Tracking.—Given the continued existence of comprehensive education to age 18, differentiating and sorting of students by abilities, interests, and preparation are inevitable. Some form of tracking is practiced everywhere, but its potency and rigidity are declining. In mathematics and science, tracking favors those who show early, recognizable academic talent and are selected into the college-bound, mathematics- and science-intensive path of the academic track. When practiced from an early age, tracking erodes the self-confidence of lower-tracked students and can cramp academic potential, often suppressing the expression of talent when applied too rigidly.

The need is to break down the rigidity of tracks, build pathways between them, and improve the sorting of talent between tracks. Tracking based exclusively on IQ and multiple-choice achievement tests

Photo credit: William Mills, Montgomery County Public Schools

The curriculum development projects funded by the National Science Foundation in the 1960s, such as this one in physics, have generally proved to be successful, but only when teachers have been well trained and supported in the use of the new materials.

penalizes some groups of students. Although the alternatives lie in the hands of schools and teachers, the Federal Government could do the following:

- provide incentives, including financial ones, for school districts to improve the efficiency of sorting between tracks and to use better techniques for identifying potential talent; and
- continue to fund and disseminate research on tracking, and its particular effects on mathematics and science instruction, and on women and minorities.

Revise Testing Procedures and Tools.—The current national system of testing, which relies on standardized multiple-choice questions, is simple to administer, inexpensive, and is seen as largely scientificially objective. It has many harmful effects, however. It puts pressures on teachers to "teach to the test," and on students to learn for the test, emphasizing parrot-like repetition of facts at the expense of so-called higher-order thinking skills. It appears also to discriminate against those not exposed to certain courses and lacking test-taking skills. In mathematics and science, it emphasizes the contemporary belief that science is a system of facts to be memorized, rather than a system of tentative beliefs and a framework for understanding natural phenomena.

Testing could be improved by emphasizing:

- written responses, as well as multiple-choice questions;
- higher-order thinking skills, i.e., deductive and lateral thinking;[23]
- oral skills, using oral tests; and
- experimental and deductive skills, by doing experiments and practical manipulations in examinations.

The most likely Federal role in testing reform is supporting research on alternative forms and uses of testing, and in disseminating "better" tests. Refinement of the National Assessment of Educational Progress should continue, with special emphasis on eliminating any gender and ethnic biases and a search for more useful, wide-ranging test instruments.[24]

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[23] The National Research Council's Committee on Indicators of Precollege Science and Mathematics Education has proposed a national research center to facilitate the creation of student and teacher tests, especially measures of the higher-order thinking skills of students in kindergarten through grade five. These would augment, if not replace, multiple-choice tests. See National Research Council, *Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12* (Washington, DC: National Academy Press, 1988).

[24] See *FairTest Examiner*, "FairTest Wins NAEP Reforms: More Problems Remain," winter 1988, p. 3. The National Assessment of Educational Progress has already begun testing of hands-on skills in science.

MANAGEMENT OF FEDERAL SCIENCE AND ENGINEERING EDUCATION

Federal agency leadership and interagency coordination are needed to raise the visibility of science and engineering education. The collection, dissemination, and use of data for evaluating outcomes and developing new programs are essential for improving the reach and content of science and engineering education.

1. Strengthen National Science Foundation Leadership in Science Education

Federal responsibility for the long-term health of the system of science education, from the early grades through postdoctorate study, rests in the hands of NSF. NSF has been the lead agency, ever since its inception, in Federal initiatives to improve science education, and has administered most Federal science and engineering education programs. Such programs form part of NSF's overall mission to support the education and training of research scientists and engineers and to promote basic research.[25]

Under its broad charge, NSF has supported, largely through the Science and Engineering Education (SEE) Directorate, a range of efforts to improve precollege and college science and mathematics education including:

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[25] The National Institutes of Health spend more on such programs than the National Science Foundation does, although this funding is concentrated on graduate and postgraduate education. Other agencies also spend significant sums on education programs, primarily in order to interest young students in scientific and engineering careers or to channel students into particular fields.

- teacher institutes;
- curriculum development;
- student research;
- research, evaluation, and testing of advanced teaching technologies; and
- encouragement of partnerships among business, industry, professional associations, civic groups, and local schools to sustain the above activities.[26]

In addition, NSF has supported the familiar graduate fellowships, RAs, and traineeships administered by the research directorates.

Having a strong, central, competent, committed administrative home is crucial to the implementation of Federal science education programs. In addition, because of the local nature of American education, a visible national focus is important to provide leadership to support, inform, and capitalize on the many local initiatives that dominate American education. At NSF, with its commitment to the basic research community, the traditional emphasis on research and graduate education has been largely divorced from its elementary, secondary, and undergraduate education programs.

- Reinforce NSF's role as lead agency for Federal science and engineering education activities by altering NSF's administration of these activities.
- Require NSF to employ more staff experienced in the practice of elementary and secondary education in schools, school districts, and State education agencies, rather than those recruited from research environments in higher education.

There is no single home or central coordination for human resource programs at NSF. In addition to the SEE Directorate, considerable funds are spent by the other directorates on education and human resource programs and by research grants that fund RAs. NSF regards teaching and research to be inseparably related activities at the higher level of the education system, and is sensitive to the variability of educational problems from discipline to discipline. Thus, NSF considers it best for the research directorates to control programs with joint educational and research objectives.

Consider the main types of NSF programs that contribute to science and engineering education:

- direct support of educational initiatives, such as teacher institutes, curriculum development, and fellowships;
- support for research activities that have educational benefits, such as research projects in general or research participation by particular groups (such as undergraduates, high school students, or teachers); and
- support to enhance the opportunities for certain populations and types of institutions to do high-quality research through grants designed to improve or sustain research capability.

Taken together, support for these activities is often labeled as being for "Education/and Human Resources." NSF's fiscal year 1988 spending for programs of this kind will be over $350 million, of which $139 million is spent through the SEE Directorate. The difference between these two sums arises from the education and human resource spending of the research directorates, which includes programs in undergraduate science education, the Presidential Young Investigator program, and other programs intended to provide seed and institutional research support for either specific groups of researchers or institutions. Even then, NSF's designation of Education and Human Resources does not include the amount of NSF research awards that is spent on providing RAs to graduate students (an estimated $120 million in fiscal year 1988). At the precollege level, the research directorates spend nothing, so all of that funding comes from SEE. Table 4-4 indicates the distribution of these funds by educational level, showing that the bulk of the broad category of "Education and Human Resources" funds goes to graduate and postgraduate education.

NSF spending on science and engineering education through SEE has fluctuated (see table 4-5, for fiscal years 1983-1988). Its golden years were the late 1950s and early 1960s, when never less than one-third of NSF's total budget went to its SEE Directorate. In later years, although SEE spending increased (reaching a peak of $134 million in fiscal year 1968), overall NSF spending rose even faster, giv-

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[26] Ben Brodinsky, *Improving Math and Science Education: Problems and Solutions* (Arlington, VA: American Association of School Administrators, 1985).

Table 4-4.—National Science Foundation Fiscal Year 1988 Spending and Fiscal Year 1989 Requested Funding for Education, by Level of Education (in millions of dollars)

	Funds from the SEE Directorate		Funds from other Directorates	
	1988	1989	1988	1989
Precollege	$90.0	108.5	0	0
Undergraduate	19.0	23.5	21.0	41.4
Graduate fellowships, etc.	30.3	24.0	2.5	2.7
research assistantships	0	0	119.0	125.0 (est.)
Postdoctoral, including Presidential Young investigators	0	0	52.9	58.7
Research initiation and broadened participation in research	0	0	22.7	27.0
Totals	$140.3	156.0	217.1	255.0

SOURCE: Office of Technology Assessment estimates based on personal communications with the National Science Foundation, Office of Budget, Audit, and Control, 1988.

Table 4-5.—Requests, Appropriations, Spending, and Unobligated Funds for the National Science Foundation's Science and Engineering Education Directorate, Fiscal Years 1983-88 (in millions of dollars)

	Fiscal years					
	1983	1984	1985	1986	1987	1988
Request	$15.0	$39.0	$75.7	$50.5	$89.0	$115.0
Appropriation	30.0	75.0	87.0	55.5	99.0	139.0
Actual spending	16.0	57.0	82.0[a]	84.0	99.0	
Unobligated (carried forward)	14.0	32.0	32.0	—	—	

[a] In fiscal year 1985, $5 million was transferred by the Science and Engineering Education Directorate to the Biological, Behavioral, and Social Sciences Directorate for support of a program on Research in Teaching and Learning.

SOURCE: Laurie Garduque, "A Look at NSF's Educational Research Budget," *Educational Researcher*, June-July 1987, pp. 18-19, 23. Based on *National Science Foundation Budget Summary, Fiscal Year 1983* (and annual volumes through 1988).

ing education a declining share. After fiscal year 1968, SEE spending fell every year until 1974, and held level in the 1970s at about $60-$80 million annually. In fiscal year 1982, the Reagan Administration attempted to cut out NSF's education spending altogether; at its nadir, the SEE Directorate funded only a reduced program of graduate fellowships. Since 1982, however, the SEE Directorate has slowly been resuscitated and will be funded at $139 million in fiscal year 1988. This appropriation, in actual dollars, is the largest ever in the history of SEE. The majority of SEE's spending is on K-12 programs.

Table 4-5 indicates that, in each year from 1983 to 1988, Congress appropriated between 10 and 100 percent more than NSF requested for the SEE Directorate. It also indicates that, in fiscal years 1982-1984, NSF did not spend all that it was appropriated and carried forward never less than 35 percent of each year's appropriation to the next fiscal year. Data on education spending in the research and related directorates appear in table 4-6. It is estimated that, in fiscal year 1987, NSF spent over $200 million on education in these directorates.

Persistent issues that arise in NSF's science and engineering education programs are:

- The balance to be struck between programs for the elite of potential researchers and the mass of science learners in schools and colleges who are less likely to become scientists. A recent congressionally mandated review urged that NSF "take the lead nationally in broadening the base

Table 4-6.—National Science Foundation Education Spending by the Research and Related Directorates, Fiscal Years 1982-87 (in millions of dollars)

	Fiscal years					
Level of education	1982	1983	1984	1985	1986	1987 (est.)
Postdoctoral	$43.0	$44.2	$51.0	$56.5	$56.0	$58.4
Graduate students (including RAs)	72.2	76.6	90.8	102.3	107.0	115.4
Undergraduate:						
Students	n.a.	n.a.	n.a.	7.9	8.0	19.5
Faculty	1.0	1.0	8.2	10.2	12.4	15.9
Totals	116.2	121.8	150.0	176.9	183.4	209.2

RAs = research assistantships.
n.a. = not available.

SOURCE: National Science Foundation Office of Budget, Audit, and Control; personal communication to Office of Technology Assessment, January 1988.

of science learners as their primary mandate rather than 'skimming the cream'."[27]

- The coordination of NSF education programs. Education groups, such as the National Science Teachers Association, urge that all funding for K-12 and undergraduate science and engineering education should be coordinated under a single head. NSF argues that the unique nature of advanced education in the sciences and engineering, which involves the union of teaching and research, means that some education functions are best conducted through the research directorates.
- Concern that the research-oriented culture of NSF skews the operations of SEE and other science education activities, and discourages SEE from undertaking any kind of replication of successful programs in favor of one-of-a-kind "experimental" research projects.
- Concern about transfers of funds from SEE to the research directorates, to be spent on research rather than education. Other than a $5 million transfer in fiscal year 1985 for a program of research in teaching and learning, there is no evidence that such transfers have occurred.

As it stands, particularly in the undergraduate area, science and engineering education appears to gain a bonus from the education programs conducted in the research and related directorates. In the case of undergraduate science education, NSF has created a new Office of Undergraduate Science, Mathematics, and Engineering Education to coordinate activities from all across NSF. Because NSF does use funds from research directorates to fund science and engineering education, there is a danger that any increases in the annual appropriation to the SEE Directorate will merely displace spending from the research directorates and not lead to a net increase in science and engineering education spending. For example, in fiscal year 1988, some activities, such as undergraduate curriculum reform efforts that were to be funded through the research directorates, will be funded through SEE (although the funding will still be controlled largely by the relevant research directorates). In fiscal year 1988, such reallocation of spending will only amount to a few million dollars.

Given the history of science education at NSF, some believe that its priority will be assured only by creation of a separate board, patterned on the National Science Board. Such a board would oversee all science education activities. Whether this board would be of status equal to the National Science Board, and how its decisionmaking and budget authority would be reflected in a revised table of organization for the National Science Foundation, are just two issues that deserve serious congressional consideration. A separate board would ensure that funding for science and engineering education and other human resource programs is centrally coordinated through the SEE Directorate, rather than being dispersed across the research directorates of NSF.

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[27] Michael S. Knapp et al., *Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation*, vol. 1 (Menlo Park, CA: SRI International, June 1987), p. 6.

2. Improve Federal Interagency Coordination and Data Collection

Coordinating related programs among Federal agencies is a perennial problem in all mission areas, not just education and research. To facilitate coordination, information sharing, and to avoid fruitless duplication, Congress has mandated various forms of organized consulting mechanisms, such as interagency coordinating committees. Ad hoc, informal communication among colleagues—telephone calls, meetings, etc.—is as important as formal communications. Coordinating committees have been most commonly used in areas undergoing significant change, such as areas of new Federal involvement and regulation, or with important public or foreign policy interest (such as biotechnology). In science and engineering education, there seems to be no such motivation for extensive formal coordination. Congress could change the tone, if not the motivation, for interagency coordination.

Using the unique aspects of the education programs sponsored by the mission agencies could be an essential part of coordination. Regional laboratories and centers often develop close ties to local schools and universities. Mission R&D has an inherent attraction to youngsters (for example, space, aeronautics, and nuclear power) lacking in the basic research that NSF funds. The mission agencies also monitor and analyze their personnel needs, as in the Department of Energy-supported data series on energy-related manpower. (Although not a Federal agency, the Institute of Medicine likewise sets a high standard with its analysis of biomedical and behavioral research personnel supply and demand.)[28] Such planning may be easier to do in a narrow, applications-oriented field than for science and engineering as a whole.

Mission agencies should have the authority and funds to capitalize on their strengths, including science education. Often they must scavenge education money from research programs. NSF is needed to ensure the renewal of the research work force for basic, long-term research; the mission agencies need to handle their shorter-term, more volatile science and engineering personnel needs.

There is also no comprehensive and systematic summary of all Federal science and engineering education programs. Many Federal agencies involved in scientific and engineering activities have education programs, but these programs are not centrally coordinated. The National Science Foundation collects and publishes reliable data on the funding provided by each Federal agency for R&D at universities and for support of graduate students. These data also include funding for instructional equipment. Although NSF has historically been the lead agency for science and engineering education programs, more funds for such programs are provided by NIH than by NSF.

- Raise the level and visibility of interagency planning and coordination of science and engineering education programs. Foster informal exchanges of ideas and information among NSF, the Department of Education, and the mission agencies. Establish a Federal coordinating committee on science and engineering education among these agency representatives.
- Attach higher visibility to science and engineering education programs (and possibly expand them) in R&D mission agencies by requiring reports or by giving such education programs line items in budget proposals.
- Require NSF to assemble a biennial report on the overall state of Federal programs in science and engineering education. Or ask the Office of Management and Budget to do a special budget analysis on Federal science and engineering education, which would tabulate the net result of all types of programs, categorized by level of education and the destination of funding (including students, faculty, and institutions).
- Support data collection, analysis, and dissemination at the Department of Education and NSF, especially longitudinal studies.
- Redivide NSF and Department of Education data responsibilities by mandating reports, allotting budgets, and requiring the Department to collect science and engineering education data.

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[28] U.S. Department of Energy, *Energy-Related Manpower 1986* (Washington, DC: annual); and Institute of Medicine, *Personnel Needs in the Biomedical and Behavioral Sciences 1987* (Washington, DC: biennial).

- Continue to revamp the National Center for Education Statistics.[29]
- Improve the use of education data, in particular, information dissemination and technology transfer of successful research and practice. Expand the Department of Education's National Diffusion Network and support networking efforts (through agency funding of newsletters, professional societies, and conferences).

Department of Education Contributions

Occasional proposals have been made to move lead Federal responsibility for precollege science and mathematics education from NSF to the Department of Education. Proponents of such a step cite the massive funding that flows through the Department, and its extensive ties to local school districts and other education authorities. The Department of Education has been concerned mainly with the welfare of the education system as a whole. The large formula grant and student aid programs it administers already make substantial demands on its resources. As the agency most closely associated with the scientific research community, NSF has remained the administrative home of, and lead agency for, precollege science and engineering education.

At the undergraduate level, the Department of Education could enlarge its contribution through greater emphasis on science and engineering programs and students, for example, by using its resources to advertise and build on NSF pilot programs and research. The Department also administers programs to develop local activities in science and engineering education, primarily under Title II of the Higher Education Act of 1965. Such programs to support science and engineering dents as a population meriting special attention in the national interest could be expanded. But shifting primary responsibility to the Department, given the changes in mission, spending, and staffing that would be required, seems unwarranted at this time.

Federal Programs: Data and Evaluation

Several studies have looked at the provisions of all Federal agencies for a particular aspect of science and engineering education,[30] and some agencies publish reports that describe their own programs.[31] Appendix B lists the major Federal science and engineering education programs along with their current levels of effort and estimated numbers of students or institutions served. While collating such information on a regular basis would take time and money, it might help Federal policymakers coordinate the regions, populations, and institutions affected by Federal programs and to identify groups that have "fallen through the cracks" of the different agencies. A one-time in-depth review of science, mathematics, and engineering education support, including the role of agency research programs in education, might also be fruitful.

The Department of Education and NSF have long collected data relevant to their respective missions—the Department of Education on the condition of elementary, secondary, higher, and vocational education, and NSF on higher education of research scientists and engineers.[32] Three national longitudinal studies have provided valuable information on students moving through the educational system.[33] NSF data and analysis on U.S. science and engineering is widely used and internationally emulated. In general, however, the production of statistical and evaluative information on education has declined noticeably in the last decade.[14]

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[29] National Research Council, *Creating a Center for Education Statistics: A Time for Action* (Washington, DC: National Academy Press, 1986).

[30] See, for example, U.S. General Accounting Office, *No Federal Programs Are Designed Primarily to Support Engineering Education, But Many Do*, GAO/PAD-82-20 (Washington, DC: U.S. Government Printing Office, May 14, 1982); and U.S. General Accounting Office, *University Funding: Federal Funding Mechanisms in Support of University Research*, GAO/RCED-86-53 (Washington, DC: U.S. Government Printing Office, February 1986).

[31] See, for example, U.S. Department of Energy, *University Research and Scientific Education Programs of the U.S. Department of Energy*, DOE/ER-0296 (Washington, DC: U.S. Government Printing Office, September 1986). The National Science Foundation collects extensive information on its own programs and publishes some of it.

[32] A 1987 Rand Corp. study to explore indicators for the performance of precollege mathematics and science education in the United States called for development of a comprehensive indicator system and offered several options for improving the National Science Foundation's current ad hoc data collection and analysis efforts. See Joseph Haggin, "Assessment of Precollege Science Training Probed," *Chemical & Engineering News*, Oct. 12, 1987, pp. 20-21.

[33] These are the National Longitudinal Survey (following the 1972 high school senior class), High School and Beyond (following 1980 high school sophomores and seniors), and the National Education Longitudinal Survey (beginning in 1988).

Data help policymakers identify trends and evaluate the impact of programs. However, large amounts of new national-level data would be expensive and are not desperately needed. New data collection is a burden to Federal agencies and the information sources (usually schools and universities); education data from mission agencies should minimize new reporting requirements (information can be extracted from existing proposal and reporting data). Systematic evaluation of education programs would provide accountability and information on what works. (There are some models: at the precollege level, the Department of Education's *What Works* series, and in higher education, evaluations of NSF's Science Development Program and University-Industry Cooperative Research Centers.) Modest evaluation of student support mechanisms would also be useful. Better, more timely data based on careful survey and analysis design and budget allocation are needed. Even more pressing is better dissemination and use of the data that already exist.

Congress can continue oversight of data collection and management, the use of data in program evaluation and design, and be unflagging in its call for education data. The Federal Task Force on Women, Minorities, and the Handicapped in Science and Technology is another impetus for the collection and analysis of information. Efforts such as this, in turn, should mobilize the research community, perhaps through umbrella organizations such as the American Association for the Advancement of Science,[15] to take a greater interest—as information clearinghouses and symbolic leaders—in science, mathematics, and engineering education. The Nation requires such a concerted effort.

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[14] U.S. General Accounting Office, *Education Information: Changes in Funds and Priorities Have Affected Production and Quality*, GAO/PEMD-88-4 (Washington, DC: U.S. Government Printing Office, November 1987). Also see Marcia C. Linn, "Establishing A Research Base for Science Education: Challenges, Trends, and Recommendations," *Journal of Research in Science Teaching*, vol. 24, No. 3, 1987, pp. 191-216.

[15] For example, see American Association for the Advancement of Science, Office of Science and Technology Education, *The Continuing Crisis in Science Education: The AAAS Responds*, A Report to the Board of Directors (Washington, DC: 1986).

Appendixes

Appendix A

Alphabetical Listing of Leading Undergraduate Sources of Science and Engineering Ph.D.s in Two Institutional Categories, 1950-75

The following alphabetical lists are based on an OTA analysis of the colleges and universities granting baccalaureate degrees to students who went on to earn a Ph.D. in science or engineering. Because large degree-granting institutions would be favored in a ranking based on the absolute number of baccalaureates produced that go on to earn Ph.D.s in science and engineering, OTA measured the contributions of baccalaureate-granting institutions to Ph.D. production, controlling for size of the institution.[1]

The 100 Most Productive Institutions

This category lists alphabetically the 100 institutions of all types with the highest ratios of baccalaureate degrees awarded (in all fields) to students who later earned science or engineering Ph.D.s (at any institution).[2]

Amherst College/MA
Antioch College/OH
Bard College/NY
Bates College/ME
Beloit College/WI
Berea College/KY
Blackburn College/IL
Bowdoin College/ME
Brandeis University/MA
Brown University/RI
Bryn Mawr College/PA
Bucknell University/PA
California Institute of Technology
Carleton College/MN
Carnegie-Mellon University/PA
Case Western Reserve University/OH
Centre College of Kentucky
City University of New York
Clark University/MA
College of Charleston/SC
College of Wooster/OH
Colorado School of Mines
Columbia University/NY
Cooper Union/NY
Cornell University/NY
Dartmouth College/NH
Davidson College/NC
Delaware Valley College/PA
Drew University/NJ
Duke University/NC
Earlham College/IN
Eckerd College/FL
Franklin and Marshall College/PA
Grinnell College/IA
Hamilton College/NY
Hampshire College/MA
Harvard University/MA
Harvey Mudd College/CA
Haverford College/PA
Hope College/MI
Illinois Benedictine College
Illinois Institute of Technology
Iowa State University
The Johns Hopkins University/MD
Juniata College/PA
Kalamazoo College/MI
Kenyon College/OH
King College/TN
Knox College/IL
Lafayette College/PA

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[1] Betty D. Maxfield, "Institutional Productivity: The Undergraduate Origins of Science and Engineering Ph.D.s," OTA contractor report, July 1987. Baccalaureates awarded are based on the Department of Education's National Center for Statistics institutional counts, reported in *Earned Degrees Conferred*. Six academic years were sampled in this analysis for baccalaureate data: 1950, 1955, 1960, 1965, 1970, and 1975. All baccalaureate information was matched (through 1986) with Ph.D. data from the National Research Council's Doctorate Records File, which is based on annual Surveys of Earned Doctorates. New Ph.D. recipients, in cooperation with their institutions' graduate studies offices, complete questionnaires that provide basic demographic, educational, and planned employment characteristics. This information is the basis of the Ph.D. counts used in calculating the institutional ratios of science and engineering Ph.D.s per 100 baccalaureates.

[2] These 100 include the 15 "technical" institutions (that emphasize science or engineering) whose productivity was shown separately in figure 3-6. The ratio of science and engineering Ph.D.s earned per 100 baccalaureate degrees awarded by these institutions range from 4 to 44.

Lawrence University/WI
Lebanon Valley College/PA
Lehigh University/PA
Macalester College/MN
Massachusetts Institute of Technology
Muhlenberg College/PA
New Mexico Institute of Mining and Technology
Oberlin College/OH
Occidental College/CA
Philadelphia College of Pharmacy and Science/PA
Pitzer College/CA
Polytechnic University/NY
Pomona College/CA
Princeton University/NJ
Radcliffe College/MA
Reed College/OR
Rensselaer Polytechnic Institute/NY
Rhodes College/TN
Rice University/TX
South Dakota School of Mining and Technology
Stanford University/CA
State University of New York at Binghamton
State University of New York, College of Environmental Science and Forestry
State University of New York at Stony Brook
Stevens Institute of Technology/NJ
St. Johns College/MD
Swarthmore College/PA
Union University/NY
United States Merchant Marine Academy/NY
United States Military Academy/NY
University of California at Berkeley
University of California at Davis
University of California at Irvine
University of California at Los Angeles
University of California at Riverside
University of California at San Diego
University of California at Santa Cruz
University of Chicago/IL
University of Rochester/NY
University of South Florida, New College
Vassar College/NY
Wabash College/IN
Webb Institute of Naval Architecture/NY
Wellesley College/MA
Wesleyan University/CT
Whitman College/WA
Williams College/MA
Worcester Polytechnic Institute/MA
Yale University/CT
Yeshiva University/NY

49 Liberal Arts Colleges

The 50 liberal arts colleges that participated in the Second National Conference on "The Future of Science at Liberal Arts Colleges" at Oberlin College in June 1986 defined this list (presented alphabetically).[1]

Albion College/MI
Alma College/MI
Amherst College/MA
Antioch College/OH
Bates College/ME
Beloit College/WI
Bowdoin College/ME
Bryn Mawr College/PA
Bucknell University/PA
Carleton College/MN
Colgate University/NY
College of the Holy Cross/MA
College of Wooster/OH
Colorado College
Davidson College/NC
Denison University/OH
Depauw University/IN
Earlham College/PA
Franklin and Marshall College/PA
Grinnell College/IA
Hamilton College/NY
Hampton University/VA
Harvey Mudd College/CA
Haverford College/PA
Hope College/MI
Kalamazoo College/MI
Kenyon College/OH
Lafayette College/PA
Macalester College/MN
Manhattan College/NY
Middlebury College/VT
Mt. Holyoke College/MA
Oberlin College/OH
Occidental College/CA
Ohio Wesleyan University
Pomona College/CA
Reed College/OR
Smith College/MA

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[1] However, Barnard College's baccalaureate counts were not reported separately from Columbia University. Thus, the 50 private liberal arts colleges, sometimes referred to as "research colleges" because of their emphasis on undergraduate and faculty research, were reduced to 49. The ratios of science and engineering Ph.D.s earned per 100 baccalaureates awarded by these institutions vary from 1 to 30.

St. Olaf College/MN
Swarthmore College/PA
Trinity College/CT
Union University/NY
Vassar College/NY
Wabash College/IN
Wellesley College/MA
Wesleyan University/CT
Wheaton College/IL
Whitman College/WA
Williams College/MA

Appendix B

Major Federal Science and Engineering Education Programs

The following information, in fiscal year 1988 obligations where possible, shows approximate Federal support of science and engineering education programs by agency and type of program. Obligations are the amount that an agency commits to spend out of its budget; the actual amount of funds spent may differ somewhat from the amount obligated. There may be large variations from year to year in agency budgets due to changes in congressional appropriations or legislation creating and eliminating programs. Changes in agency priorities also affect funding levels.

The estimates in this table are based on information provided to OTA by staff responsible for education, university relations, research and development (R&D), and/or personnel at each of the departments listed, supplemented by published sources. This table is not the result of an exhaustive survey, but does indicate the breadth and diversity of Federal support across the agencies for science and engineering education. Because of differences in recordkeeping, it is difficult to make precise statements on spending.

The programs listed are of several types: 1) the educational programs of the Department of Education and Veterans Administration that support all students and institutions, including but not specifically targeted to science and engineering; 2) agency support of university research, which indirectly funds students (as research assistants); and 3) special programs, usually much smaller in scope and budget, which have the support of science and engineering education as their primary goal. Faculty programs are not included. The left hand column lists the funding department and major programs, according to the educational level served (postgraduate, graduate, undergraduate, precollege, institutional). The two right hand columns list, respectively, estimated 1988 agency obligations and the number of science or engineering students (noted with an "s") or institutions (noted with an "i") that receive funds or participate in the program. The obligations and students listed are *only* those related to science and engineering (including social sciences). Our inability to estimate obligations or students is indicated by —.

Department and major programs	**1988 budget (estimated, in millions of dollars, where noted)[1]**	**Number of students or institutions supported**
	(science/engineering-related only)	
U.S. Department of Education		
• Graduate and Professional Opportunities Program (about 1/2 are in science/engineering (s/e))	6 M	700 s
• Cooperative education (Title VIII, Higher Education Act) (1/3 to 1/2 is s/e)	5-7 M	100,000 s 105 i
• Title II, Education for Economic Security Act		
—State grants (teacher training, supplies)	109 M	—
—magnet schools (@30% of total $72 M)	22 M	—
• Discretionary programs (total $11 M)		
—television, e.g., "3-2-1 Contact"	3.25 M (1987)	—
—National Diffusion Network, miscellaneous programs, e.g., Physics Teach to Learn, CADPP (elementary mathematics)	—	—
Institutional		
• Minority Institutions Science Improvement Program (MISIP)	5 M	180 i

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[1] Based on OTA personal communications with Federal agency staff. Additional published sources are National Science Foundation, *A Directory of Federal R&D Agencies' Programs to Attract Women, Minorities, and the Physically Handicapped to Careers in Science and Engineering*, NSF 85-51 (Washington, DC: 1985); and U.S. General Accounting Office, *Federal Funding Mechanisms in Support of University Research*, GAO/RCED-86-53 (Washington, DC: 1986).

The Department of Education spends billions of dollars on education, some of which goes to science and mathematics programs, teaching, education research, and computer technology. These include programs such as Chapter 1 and Chapter 2, student and institutional aid, and more likely sources of science/mathematics improvement or seed money such as the Office of Educational Research and Improvement ($67 million) or the Fund for the Improvement of Postsecondary Education ($11 million). Two centers dedicated to the study of mathematics and science teaching and learning were added in 1988 to the roster of 19 National Educational Research Centers; each of the 2 has a budget of $500,000. One of the ERIC clearinghouses of educational research and information is dedicated to science, mathematics, and environmental education. Together these large, broad support programs and other discretionary or general programs provide extensive funds for science and mathematics education. Discretionary funds may in particular be applied to seed programs. It is impossible to quantify the amount or directness of support for science and mathematics education from these large national programs, many of them formula programs. One approach is to estimate that 15 to 40 percent of funding is relevant to science and mathematics education.

Department and major programs	**1988 budget (estimated, in millions of dollars, where noted)[1]**	**Number of students or institutions supported (science/engineering-related only)**
National Institutes of Health (NIH)		
Postdoctorate		
• National Research Service Awards Postdoctoral Fellowship Grants (includes M.D.-Ph.D., about 50% of total)	130 M	5,800 s
Graduate		
• National Research Service Awards Predoctoral Training Grants	100 M	5,200 s
• Research assistants (RAs) on research grants (@ 5-15% of academic R&D)	150-450 M	7,000 s
• Minority Access to Research Careers (MARC) Predoctoral fellowship	665,000	68 s
Undergraduate		
• MARC Honors Undergraduate Research Training	6.3 M	385 s
• National Institutes of Mental Health Minority Fellowships	1.8 M	150 s
Precollege		
• NIH Minority High School Student Research Apprenticeships	1.5 M	410 s
Institutional		
• Minority Biomedical Research Support (MBRS)	28 M	100 i
—Regular MBRS program projects	—	450 s
—Undergraduate Biomedical Research Participation	—	1,200 s
—Supplemental Awards for Improvement of Animal Resources and Facilities	—	—
• Research Centers for Minority Institutions	5 M	100 i
National Science Foundation (NSF)		
Postdoctorate		
• Presidential Young Investigators	40 M	800 s
• Postdoctorates (six programs)	58 M	80 s
• NATO postdoctorates (NATO funds, supplemented by NSF)	—	50 s

Department and major programs	1988 budget (estimated, in millions of dollars, where noted)[1]	Number of students or institutions supported (science/engineering-related only)
Graduate		
• Graduate RAs on research grants	120 M	8,300 s
• Supplemental funding for minority/women RAs	—	—
• Dissertation improvement	1.2 M	190 s
• Graduate fellowships		
—Graduate fellowships	25 M	700 s
—Minority graduate fellowships	2.7 M	75 i
Undergraduate		
• Engineering Undergraduate Creativity Awards	2 M	30 s
• Undergraduate research experience	9 M	2,800 s
• Career access for women, minorities, and the disabled	2 M	—
• College Science Instrumentation Program	12 M	—
• Curriculum development	7 M	—
Precollege		
• High school research experience		
—Young Scholars	3.7 M	1,600 s
—RAs for minority high school students	100,000	—
• Informal education	13.5 M	—
• Materials development	20 M	—
• Teacher preparation and enhancement	45.5 M	—
• Research in teaching and learning	4 M	—
U.S. Department of Energy		
Graduate		
• Graduate fellowships	1.4 M	70 s
• Summer research support	—	2,000 s
• RAs on research grants (@5-15% of $350 million university R&D)	15-50 M	3,500 s
Undergraduate		
• Science and Engineering Research Semester	600,000	115 s
• Summer research internship	3 M	1,000 s
• Co-op/Junior Fellows	—	50-65 s
Precollege		
• Prefreshman Engineering Program (PREP)	300,000	2,000 s
• High School Honors Research Program	550,000	320 s
• Minority Student Research Apprenticeships	120,000	200 s
• Precollege teacher training and research (summer research experience at labs, short courses, materials)	250,000	50 teachers
Institutional		
• HBCU	12 M	—

The Department of Energy has a University-Laboratory Cooperative Program, which includes faculty, research, and institutional development programs in addition to the undergraduate and graduate summer research programs noted above. Of a total budget of $8.8 million, about $2.5 million goes to science education centers being developed with the national laboratories, and about $6.3 million to summer research programs and other science education programs. DOE and the national laboratories also have many volunteer outreach and technical assistance programs, such as Partnership in Education (adopt a high school).

Department and major programs	1988 budget (estimated, in millions of dollars, where noted)[1] (science/engineering-related only)	Number of students or institutions supported (science/engineering-related only)
Department of Defense (DoD)		
Graduate		
• Graduate RAs on research grants (@ 5-15% of academic research)	50-150 M	4,000-5,000 s
Undergraduate		
• Reserve Officers Training Corps (ROTC) (75% of Air Force and 80% of Navy ROTC funds are set aside for technical majors)	—	21,000 s
• JETS/UNITE (Uninitiated Introduction to Engineering)	—	—
• Co-op/Junior Fellows	—	2,500-3,000 s
Precollege		
• Research and Engineering Apprenticeship (REAP) (at DoD laboratories)	—	—
• Extensive informal outreach: career fairs, science fairs and awards, recruitment		
Air Force/Air Force Office of Scientific Research		
• Air Force laboratory postdoctoral scholar programs	3 M	—
• Graduate fellowships	1.5 M	75 s
• Graduate Student Summer Support Program (laboratory employment for graduate students)	—	100s
• High school apprenticeship (summer jobs at laboratories; primarily minorities)		
Army/Army Research Office (ARO)		
• Army Graduate Fellowship Program (no continuing funds appropriated)	7 M	36 s
• REAP	275,000	140 s
• Introduction to Engineering (UNITE) (6 residential programs for minorities)	100,000	150-180 s
• Junior Science and Humanities Program symposia (research talent search)	750,000	7,000 s
• Computer-Related Science and Engineering Studies (CRES) (4 residential weeks at universities)	50,000	60 s
• Science and Engineering Fair Program, International Mathematical Olympiad (ARO contributes awards, judges)	50,000	500,000 s
Navy/Office of Naval Research		
• Young Investigator Program (10-30 new multiyear awards each year)	2.5 M	50 s
• Graduate fellowships (45-50 new multiyear awards each year)	25 M	150 s
• High School Apprentice Program (mentored summer work in labs; targets inner-city, minorities, disadvantaged)	120,000	130 s

Department and major programs	1988 budget (estimated, in millions of dollars, where noted)[1]	Number of students or institutions supported (science/engineering-related only)
• Historically Black College Council (seeds research programs, graduate fellowships, summer faculty research, research instrumentation, high school apprenticeships)	2.6 M	17 i
Strategic Defense Initiative Office/ University Research Initiative		
• Graduate RAs on research grants (@ 10-15% of $50 M academic research)	5-7.5 M	600 s
Institutional		
• HBCUs	—	—
Manpower/Education Research		
• Center for the Advancement of Science, Engineering and Technology (CASET)	1 M	—
National Aeronautics and Space Administration (NASA)		
Postdoctorate		
• Postdoctoral research associateship (1 year of research at NASA)	12 M	200 s
Graduate		
• Graduate student researchers fellowships (1 year thesis research support)	4.8 M	240 s
• Minority graduate fellowships	2 M	60-110 s
• Graduate RAs on research grants (@ 8% of academic R&D)	22M	—
Undergraduate		
• Education and curriculum research	4.7 M	—
• Co-op/Junior Fellows	—	1,100-1,200 s
Precollege		
• Aerospace Education Services (Spacemobile)	2.1 M	—
• Innovative programs —NASA Education Workshops for Mathematics and Science Teachers (NEWMAST) —NASA Education Workshops for Elementary School Teachers (NEWEST) —Space Science Student Involvement Program (SSIP)	1.3 M	—
• Individual NASA laboratories have many local research apprenticeships, student employment, teacher resource centers, and outreach programs		
Institutional		
• University Advanced Design Program	1.5 M	25 i
• Centers of Excellence	—	—
• Space Engineering Research Centers	4 M	10 i
• HBCUs	9 M	—
U.S. Department of Agriculture		
Postdoctorate		
• Postdoctorates (Agricultural Research Service —ARS)	—	100 s

Department and major programs	1988 budget (estimated, in millions of dollars, where noted)[1]	Number of students or institutions supported (science/engineering-related only)
Graduate		
• Graduate fellowships	2.9 M	150 s
• RAs on research grants (@10% of academic R&D)	48 M	—
Undergraduate		
• Co-op/Junior Fellows	—	500-650 s
• Summer employment	—	10,000 s
Precollege		
—4H	70-100 M	5,100,000 s
—Research Apprenticeship Program (ARS)	250,000	200 s
—Junior Fellowship	—	200 s
—Program in Agricultural and Lifesciences for Minority Students (PALMS) (career orientation)	10,000	30 s
—Beginning Agriculture Youth Opportunities (BAYOU), Southern University, LA		
—Summer Youth Enrichment, Delaware		
—Other programs include Stay In School, fairs, summer aides, D.C. Mayor's Youth Employment, high school visits, curriculum development; Forest Service teacher training and summer student programs		
Institutional		
• Cooperative State Research Service		
—Strengthening Grants for 1890s	1.9 M	—
—Morrill-Nelson ($50,000 per State)	2.6 M	—
—1890 Research Facilities	9.6 M	17 i
—Evans Allens	21.5 M	17 i
U.S. Environmental Protection Agency		
Graduate		
• RAs on research grants (@5-15% of academic R&D)	4-10 M	—
• Graduate fellowships/traineeships (in past years, $2-5 million for academic training, forecasting, and community colleges)	-0-	-0-
Undergraduate		
• Community college-based training (curriculum development, 2+2 programs)	-0-	-0-
• Minority Student Fellowship Program (summer jobs; part of Minority Institutions Assistance Program)	275,000	50-70 s
• Co-op/Junior Fellows	—	800 s
Precollege		
• Summer internships	—	—
U.S. Department of Commerce/National Oceanic and Atmospheric Administration		
Undergraduate		
• Sea Grant student assistance	1.56 M	—

Department and major programs	1988 budget (estimated, in millions of dollars, where noted)[1]	Number of students or institutions supported (science/engineering-related only)
• Co-op/Junior Fellows	—	100-250 s
Precollege		
• D.C. Career Orientation (summer work for girls and minorities)	30,000	24 s
Institutional		
• Sea Grant (entire program)	40 M	—
U.S. Department of Commerce/National Bureau of Standards		
Postdoctorate		
• Postdoctoral research fellows	—	20 s
Graduate		
• Summer program (graduate and undergraduate)		
• Graduate Engineering for Minorities (GEM)	—	2 s
Undergraduate		
• Co-op/Junior Fellows	—	100-200 s
Precollege		
• Volunteer outreach programs		
—Resource Education Awareness Program (REAP)		
—Montgomery County Science Fair		
—Career Awareness and Resource Education (CARE)	—	30,000 s
—Adventures in Science (privately run)	—	200 s
—Montgomery Education Connection		
There are also internal staff development programs, including graduate fellowships.		
U.S. Department of the Interior/U.S. Geological Survey (USGS)		
Postdoctorate		
• Resident Research Associateship Program, USGS	—	—
Undergraduate		
• Co-op/Junior Fellows	—	135 s
• Summer jobs for teachers (with National Association of Geology Teachers)	—	20-90 teachers
• Volunteer programs: science fairs, career seminars, classroom demonstrations and visits		
• HBCU (R&D, training, equipment, evaluation, education, graduate research internships)	756,000	—
• Federal Equal Opportunity Recruitment Program (FEORP) (Programs for Minority Participation in the Earth Sciences—MPES)	640,000	—
U.S. Department of Transportation		
Graduate		
• RAs on research grants (@5-15% of academic R&D)	850,000-2.6 M	—
Undergraduate		
• Undergraduate/graduate research fellowships (National Highway Institute)	250,000	15 s
• Co-op/Junior Fellows	—	300-350 s

Department and major programs	1988 budget (estimated, in millions of dollars, where noted)[1]	Number of students or institutions supported (science/engineering-related only)
Veterans Administration		
Undergraduate (assume s/e as 35% of total trainees)		
• G.I. Bill	120 M	58,500 s
• New (Montgomery) G.I. Bill	12 M	6,800 s
• Other programs:		
—Dependent's Education	33 M	13,700 s
—Vocational Rehabilitation	24 M	5,400 s
—Post Vietnam Education Assistance (DoD and trainee contributions)	56 M	25,200 s

(College level trainees only; includes some graduate; does not include vocational/technical; includes part time.)

Government-Wide Programs

Cooperative education (co-op). The Federal Government employs cooperative students at high school through graduate school levels, although the undergraduate level dominates. At the graduate level, co-op is a recruiting tool. Overall, the Federal Government employs about 16,000 co-op students in 54 agencies; about half of these are in s/e. Engineering is the largest occupation, with 28 percent of co-op students. Federal agencies consider co-op an excellent recruitment tool, but are having trouble competing with industry for good co-op students in high-technology areas. One problem is that the co-op budget fluctuates at agencies along with regular research budgets; some managers do not have money or job slots to spare. Co-op is particularly effective in providing career-related experience for minorities and women.

Junior Fellowship. Career-related summer employment for talented but needy students from high school graduation through college graduation. Junior fellowship is a recruitment tool; successful fellows are on the fast track to career appointments. OPM delegates slots to agencies, which makes fellows attractive hires for managers. There are about 2,000 Junior Fellows in 5 Federal agencies, slightly over half of them in s/e.

Stay in School. Part-time entry-level "routine" jobs for at-risk youths to keep them in school. Many employees are clerical, some are technical aides; few are in s/e.

College Work-Study Program. The Department of Education awards grants to universities to create jobs. Federal agencies can also host students. First authorized by the Economic Opportunity Act, now under the Higher Education Act, Title IV, Part C.

Federal Equal Opportunity Recruitment Program (FEORP) also known as the Affirmative Action Recruitment Program (part of the Civil Service Reform Act of 1978). Targets minorities and women. Assistance to HBCUs.

Resident (or Cooperative) Research Associateship. Postdoctoral (administered by the National Research Council). Open to non-U.S. citizens.

Summer Employment.

Appendix C

Contractor Reports

Full copies of Contractor Reports done for this project are available through the National Technical Information Service (NTIS), either by mail (U.S. Department of Commerce, National Technical Information Service, Springfield, VA 22161) or by calling them directly at (703) 487-4650.[1]

Higher Education (NTIS order *#PB 88-177 951/AS*)

1. "The Apollo Program: Science and Engineering Personnel Demand Created by a Federal Research Mission," Arnold S. Levine
2. "Institutional Productivity: The Undergraduate Origins of Science and Engineering Ph.D.s," Betty D. Maxfield
3. "The History of Engineering Education: Perennial Issues in the Supply and Training of Talent," Steven L. Goldman, Lehigh University

Elementary and Secondary Education (NTIS order *#PB 88-177 944/AS*)

1. "Images of Science: Factors Affecting the Choice of Science as a Career," Robert E. Fullilove, University of California at Berkeley
2. "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," Valerie E. Lee, University of Michigan

International Comparisons (NTIS order *#PB 88-177 969/AS*)

1. "Japan's Science and Engineering Pipeline: Structure, Policies, and Trends," William K. Cummings, Harvard University
2. "Soviet Science and Engineering Education and Work Force Policies: Recent Trends," Harley Balzer, Georgetown University

Funding for Higher Education: Part I (NTIS order *#PB 88-177 928/AS*)

1. "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-1985," Betty M. Vetter (Commission on Professionals in Science and Technology) and Henry Hertzfeld (Consultant)
2. "Science in the Steady State: The Changing Research University and Federal Funding," Edward J. Hackett, Rensselaer Polytechnic Institute

Funding for Higher Education: Part II (NTIS order *#PB 88-177 936/AS*)

1. "Industrial Support of University Training and Research: Implications for Scientific Training in the 'Steady State'," Michael E. Gluck, Harvard University
2. "Financial Assistance, Education Debt and Starting Salaries of Science and Engineering Graduates: Evidence From the 1985 Survey of Recent College Graduates," Applied Systems Institute, Inc., Richard Wabnick (Principal Investigator)

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[1] Guy R. Neave's report, "Science and Engineering Work Force Policies: Western Europe," is only available through the Science, Education, and Transportation Program office (202) 228-6920.

Appendix D
Workshop Participants

Participants in Science and Engineering Manpower Data Workshop, July 10, 1986

Alan Fechter, *Workshop Chairman*
Executive Director
Office of Scientific and Engineering Personnel
National Research Council
Washington, DC

Stig Annestrand
Committee on Science and Technology
U.S. House of Representatives
Washington, DC

Robert Armstrong
Manager, Professional Staffing
Employer Relations Department
E.I. du Pont de Nemours & Co.
Wilmington, DE

Eleanor Babco
Associate Director
Commission on Professionals in Science and Technology
Washington, DC

Myles Boylan
Policy Analyst
Policy Research and Analysis
National Science Foundation
Washington, DC

Michael Crowley
Director, Demographics Study Group
Division of Science Resource Studies
National Science Foundation
Washington, DC

Roman Czujko
Assistant Manager
Manpower Statistics Division
American Institute of Physics
New York, NY

Daniel Hecker
Supervisory Labor Economist
Occupational Outlook Division
Office of Economic Growth and Employment Projections
Bureau of Labor Statistics
Washington, DC

W. Edward Lear
Executive Director
American Society for Engineering Education
Washington, DC

Robert Neuman
Head
Department of Professional Services
American Chemical Society
Washington, DC

Vin O'Neill
Administrator of Professional Programs
The Institute of Electrical and Electronics Engineers, Inc.
Washington, DC

Peter Syverson
Director of Information Services
Council of Graduate Schools
Washington, DC

John W. Wiersma
Wiersma & Associates
Austin, TX

Participants in Engineering Education in 1997 Workshop, Sept. 9, 1987

Christopher J. Dede, *Workshop Chairman*
Professor
University of Houston at Clear Lake
Houston, TX

Howard Adams
Executive Director
National Consortium for Graduate Degrees for Minorities in Engineering
Notre Dame, IN

Amy Buhrig
Specialist Engineer
Artificial Intelligence
Boeing Aerospace Corp.
Seattle, WA

Alton Cleveland
Bechtel Eastern Power Co.
Gaithersburg, MD

George Dieter
Dean, College of Engineering
University of Maryland
College Park, MD

Steven Goldman
Director
Science, Technology and Society Program
Lehigh University
Bethlehem, PA

Lawrence Grayson
Office of the Honorable Jack Kemp
U.S. House of Representatives
Washington, DC

Robert Morgan
Professor
Department of Engineering and Policy
Washington University
St. Louis, MO

Alfred Moyé
Manager, Continuing Education
Hewlett-Packard
Palo Alto, CA

William Snyder
Dean, College of Engineering
University of Tennessee
Knoxville, TN

Bruno Weinschel
President
Weinschel Research Foundation
Gaithersburg, MD

F. Karl Willenbrock
Executive Director
American Society for Engineering Education
Washington, DC

Participants in Math and Science Education K-12: Teachers and the Future Workshop, Sept. 15, 1987

Iris R. Weiss, *Workshop Co-Chairwoman*
President
Horizon Research, Inc.
Chapel Hill, NC

Irma S. Jarcho, *Workshop Co-Chairwoman*
Chairman
Science Department
New Lincoln School
New York, NY

Rolf Blank
Director
Science/Mathematics Indicators Project
Council of Chief State School Officers
Washington, DC

Ruth Cossey
EQUALS Program
University of California
Berkeley, CA

James Gallagher
Professor of Science Education
Michigan State University
East Lansing, MI

Michael R. Haney
Coordinator, Blair Magnet Program
Montgomery County Public Schools
Silver Spring, MD

Lisa Hudson
The Rand Corp.
Washington, DC

Ann Kahn
Former President
National Parent Teacher Association
Chicago, IL

Hugh Loweth
Consultant
Annandale, VA

Barbara Scott Nelson
Program Officer
Urban Poverty Program
The Ford Foundation
New York, NY

Gail Nuckols
Member
Arlington County School Board
Arlington, VA

Louise Raphael
Mathematical Association of America
Task Force on Minorities
Science and Engineering Education Directorate
National Science Foundation
Washington, DC

Mary Budd Rowe
President, National Science Teachers Association
Professor, Science Education
College of Education
University of Florida
Gainesville, FL

Susan Snyder
Program Director
Science and Mathematics Education Networks Program
National Science Foundation
Washington, DC

Appendix E

Acknowledgments

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Patricia Alexander, Department of Education
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Myles Boylan, National Science Foundation
Peter Cannon, Rockwell International Corp.
Dennis Carroll, Department of Education
Joanne Capper, Center for Research into Practice
Sam C. Carrier, Oberlin College
Audrey Champagne, American Association for the Advancement of Science
Susan Coyle, National Research Council
Michael Crowley, National Science Foundation
Jerry Davis, Pennsylvania Higher Education Agency
Christopher J. Dede, University of Houston at Clear Lake
Linda DeTure, National Association of Research in Science Teaching
Harry Edwards, University of California at Berkeley
Marion Epstein, Educational Testing Service
Henry Etzkowitz, State University of New York at Purchase
J.D. Eveland, Technology Applications Research
Michael Finn, Oak Ridge Associated Universities
Kenneth Frank, University of Michigan at Ann Arbor
Joseph Froomkin
Samuel Gibbon, Bank Street College of Education
Dorothy Gilford, National Research Council
Edward Glassman, Department of Education
Vance Grant, Department of Education
Lawrence Grayson, Office of the Honorable Jack Kemp, U.S. House of Representatives
Michael Haney, Montgomery Blair Magnet School, Maryland
Arthur Hauptman, American Council on Education
Henry Hertzfeld
Christopher Hill, Congressional Research Service
Thomas Hilton, Educational Testing Service
Paul DeHart Hurd, Stanford University
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Linda Kato, Congressional Research Service
Dennis Keith, Immigration and Naturalization Service
Susan Coady Kemnitzer, Task Force on Women, Minorities, and the Handicapped in Science and Technology
F. William Kirsch, Center for Energy Management and Industrial Technology
Dan Kunz, Junior Engineering Technical Society
Valerie Lee, University of Michigan at Ann Arbor
Gwendolyn Lewis, The Washington Office of the College Board
Bernard Madison, National Research Council
Cheryl Mason, San Diego State University
Robert Morgan, Washington University at St. Louis
Mark Nadel, General Accounting Office
Louise Raphael, National Science Foundation
Sherman Rosenfeld, Weizmann Institute, Israel
Richard Rowberg, Congressional Research Service
James Rutherford, American Association for the Advancement of Science
Vernon Savage, Towson State University, Maryland
Anne Scanley, National Academy of Sciences
Donald Scarl, Polytechnic University of New York
Allen Schmeider, Department of Education
Joan Solomon, Oxford University, England
Samantha Solomon, Solomon Associates
Julian Stanley, The Johns Hopkins University
Jane Stutsman, National Science Foundation
Marcia Sward, National Research Council
Lori Thurgood, National Research Council
George Tressel, National Science Foundation
Howard Tuckman, Memphis State University
Bonnie VanDorn, Association of Science-Technology Centers
Leonard Waks, Pennsylvania State University
Harvey Waterman, Rutgers University
Iris Weiss, Horizon Research
Diane Weisz, National Science Foundation
James Wilson, Northeastern University
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